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Filtration and Disinfection of FARM POND WATER

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CONTENTS

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FILTRATION AND DISINFECTION OF FARM POND WATER

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INTRODUCTION

The use of farm ponds as sources of domestic water is increasing rapidly in Ohio and in the United States. A previous study (1)[2] of the physical and bacteriological quality of raw pond water showed that such water is unsatisfactory for domestic use. Further research (2) indicated that filtration and disinfection were the major problems associated with the treatment of pond water.

In 1960 a field laboratory was established at the Southern Substation, Ohio Agricultural Experiment Station, near Ripley, for the purpose of evaluating various filtration and disinfection methods under actual field conditions. Correlated studies were carried on in the laboratory at The Ohio State University. The ultimate goal of this research was the development of a water treatment system that was simple, economical, relatively maintenance-free, and operable by persons with little or no technical training.

OBJECTIVES

The objectives of this research were as follows:
(1) To determine the characteristics of the slow sand filter for the filtration of farm pond water; (2) To evaluate pressure filters, such as sand, carbon, and prefabricated cartridge filters for the filtration of farm pond water; and(3) To evaluate the effectiveness of halogen Brom-Chlor-Dimethyl-Hydantoin and chlorine compounds in the disinfection of farm pond water.

EXPERIMENTAL LAYOUT AND PROCEDURE

Pond

The majority of the filtration and disinfection studies were conducted at the Southern Substation. A description of this pond and the

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[2]Numbers in parentheses refer to references listed at end of report.

TABLE 1.—Chemical and Bacteriological Characteristics of Water from Pond at Southern Substation.[3]

	Maximum	Minimum	Average
Turbidity, units	155	2.2	14
Color, units	520	2.5	30
Solids, total mg/l[1]	166	98	137
Solids, suspended, mg/l	27	1	15
Solids, volatile, mg/l	64	11	35
Alkalinity, total, mg/l	105	59	83
Hardness, total, mg/l	124	66	100
Non-carb. hardness, mg/l	28	5	16
pH	8.5	7.2	7.9
Iron, mg/l	0.5	0.05	0.16
Manganese, mg/l	0.3	0.5	0.16
Sulfur, mg/l	31	7	16
Chloride, mg/l	7	0	2.8
Flouride, mg/l	3	0.15	0.23
Nitrate Nitrogen, mg/l	5.9	0	0.89
Coliform Bacteria, MPN/100 ml	11,000	<3	36[2]
Enterococci Bacteria, MPN/100 ml	110	<1.8	<3[2]
Total Bacteria Population, SPC/ml	5,400	12	320[2]
Thermophilic Bacteria, per ml	38	<1	2[2]
Thermoduric Bacteria, per ml	10,000	40	34[2]
Psychrophilic Bacteria, per ml	3,200	<1	5[2]

[1]mg/l — milligrams per liter

[2]median value

[3]Samples taken one foot below surface, except turbidity and color, which are from samples taken at all depths.

pond water quality have been given in a previous report (1). The chemical and bacteriological properties of the raw pond water are summarized in Table 1.

Intakes

Three types of raw water intakes were available in the pond. The surface intake was composed of a float which supported an 18-inch by 12-inch diameter fiber glass cylinder. The gravel-barrel intake was constructed from two 55 gallon steel drums filled with coarse gravel. The buried pipe intake consisted of 600 feet of perforated 1¼-inch plastic pipe buried in the bottom of the pond.

Sampling and Analytical Procedure

Samples for bacterial analysis were placed on ice immediately after collection and remained under refrigeration until analyses were made in the laboratory, usually within 24 hours. The only measurements made in the field were temperature and chlorine residual.

Tests and procedures in this report were as follows:

Turbidity—determined with a Hellige turbidimeter precalibrated by the Jackson candle.

Color (apparent)—measured using a Hellige aqua analyzer in which the color of the sample was compared with precalibrated colored disks.

Chlorine (residual)—determinations made with a Taylor slide chlorimeter. Readings made within five seconds after addition of ortho-tolidine were taken as the amount of free available chlorine. Readings taken five minutes later were considered total chlorine.

Brom-Chlor-Dimethyl-Hydantoin (residual)—determinations were made in the same manner as chlorine and with the same equipment, except that values read on the chlorine scale were multiplied by 2.

pH—determined by phenol red indicator (pH range 6.8-8.4) in conjunction with a Taylor pH slide comparator.

Odor—detected by smell and classified as follows: no odor, perceptible, and objectionable. A sample having a faint odor, but not considered objectionable, was classified as perceptible. Any sample having a strong odor or an objectionable odor was classified as objectionable.

Coliform bacteria—estimated by the conventional multiple-tube MPN method described in Standard Methods (3). The procedure employed three tubes of lactose broth per dilution and three dilutions per sample, starting with 10 ml portions. Positive presumptive tubes were confirmed in brilliant green lactose bile broth.

Enterococci—estimated by the conventional MPN method, using Winter-Sandholzer media and three tubes per dilution, starting with 10 ml portions.

Thermophilic bacteria—estimated by the standard plate count (SPC) technique as outlined in Standard Methods for the Examination of Dairy Products (4), with incubation at 55°C.

Thermoduric bacteria—estimated by the laboratory pasteurization test as described in Standard Methods (4), *i.e.,* the water sample was heated at 145°F. for 30 minutes in a David Bradley home milk pasteurizer, then the surviving bacteria population was determined by the SPC technique with incubation at 35°C.

Psychrophilic bacteria—estimated by the SPC method with incubation at 0-10°C.

Total bacterial population estimated by the SPC technique with incubation at 35°C.

Contact time—the amount of time disinfecting agent was in contact with the water was calculated by using Baumann's data on the efficiency of retention vessels commonly found in rural water supplies (5).

Ct factor—the product of the free available chlorine (mg/l) and the contact time (min.). As an example, 0.3 mg/l of chlorine and 20 minutes contact time would result in a Ct factor of 6 (0.3 x 20). The importance of this factor in determining the effectiveness of disinfection is discussed by Baumann and Ludwig (6).

Coefficient of fineness—ratio of suspended solids to turbidity.

RESULTS

The results are grouped into three major areas: (1) primary filters, (2) secondary filters, and (3) disinfection.

Primary Filters

Slow Sand Filter Studies have been made in a number of states to develop treatment methods which would render pond water suitable for domestic use. The slow sand filter has been evaluated by most of these investigators.

Amerman (7) in Indiana found that a slow sand filter was effective in reducing the turbidity of pond water to an acceptable concentration most of the year, although certain problems were encountered between mid-November and mid-March when the pond had a high turbidity. During this time the coefficient of fineness was low indicating that the turbidity was composed of very small particles.

Hodges, *et al.* (8) found that a slow sand filter after a breakin period was effective in reducing turbidity of less than 30 units to less than 10 units in a Missouri pond. The breakin period lasted until 1500 gallons per square foot of surface area had been filtered. After 2750 gallons per square foot had been filtered, the filter was cleaned by scraping ½ inch of silt and sand from the top.

Daniel (9) conducted research on the operation of slow sand filters in Oklahoma. The turbidity of pond water in that state averaged 247 units, thus was higher than in Ohio, Indiana, Iowa, or Missouri. For this reason he recommended installation of a settling tank ahead of the filter. Alum was fed to the settling tank.

Willrich (10) in his study of a slow sand filter on an Iowa farm found that it produced acceptable water as long as the filter was properly managed. The average time between cleaning was six weeks and average length of run was 2500 gallons per square foot of surface area. This quantity of water is similar to Hodges' value.

Baumann, *et al.* (11) studied the effect of prechlorination on slow sand filter performance. Prechlorination with high concentration of chlorine (8.8 mg/l) destroyed the organisms on the surface of the filter which in the past have been considered a primary factor in the efficient functioning of a slow sand filter. Their results showed further that prechlorination (1) increased the length of filter run, (2) improved turbidity removal, (3) increased bacterial reduction, and (4) reduced the depth of pentration of suspended solids into the filter.

This contradiction of the accepted theory of the mechanism of filtration[3] plus the many unanswered questions concerning the use of slow sand filters for individual water supply treatment indicated that further investigations of long duration were needed.

A steel tank was utilized as a slow sand filter (Figure 1). Forty-five feet of plastic pipe with 13/16-inch perforations coiled on the bottom of the tank served as an underdrain. The pipe was laid with the holes down. Located at one-foot intervals down the side of the tank were sampling ports. A length of ½-inch pipe perforated with holes extended into the tank from each of the ports. These were gravel packed to prevent entrance of sand. The length of these pipes varied from port to port with the longest at the bottom and the shortest at the top (Figure 1). A hose faucet was attached to the outside of the port. The flow into the tank and the water level was controlled either by a float valve or liquid level control in conjunction with a solenoid valve.

Two disinfection agents were evaluated in connection with the filter, (1) chlorine and (2) bromide-chlorine halogen. During most of the test runs, the disinfecting agents were fed into the filtered water. In two test runs the agent was added to the water ahead of the filter. In one run an organic compound, Brom-Chlor-Dimethyl-Hydantoin (BCDH) was dissolved in the water as the water passed through a bed of BCDH granules. In the second case, laundry bleach (sodium hypochorinate 5¼ percent) was diluted with tap water and fed with a positive displacement diaphragm pump.

The operational variations in the seven test runs are outlined in Table 2. Tests were begun in April 1960 and were ended in April 1963. The buried pipe intake supplied water for test 2 and 46 percent of the time for test runs 1 and 3. Of the intakes available, the buried pipe collected the poorest quality water. It was selected in order to evaluate the filter under the worst possible conditions. The surface intake which

[3]The classical explanation of water purification by slow sand filter attributes removal of suspended particles to the activity of a more or less gelatinous, biologic film developing naturally on the surface of sand (12).

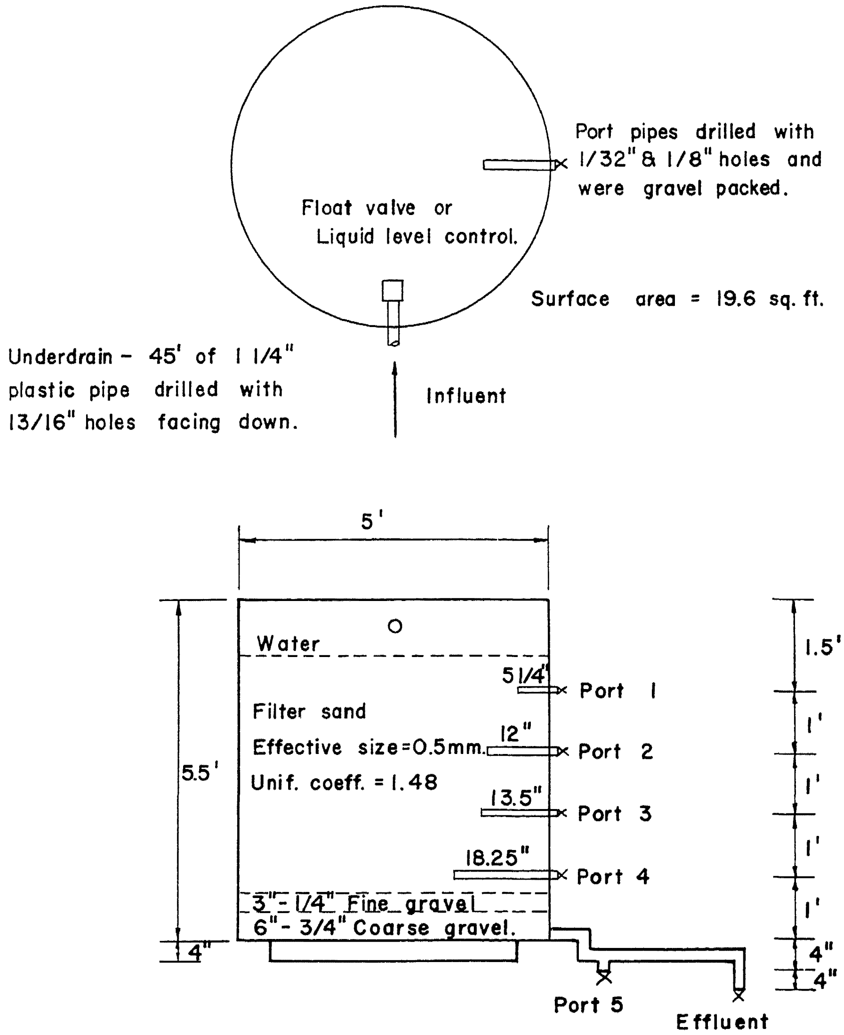

Fig. 1.—Experimental slow sand filter.

produced the highest quality of water and which is normally recommended for pond water treatment systems was utilized in the last two runs in order to study filter efficiency under ideal conditions.

Normally a slow sand filter is cleaned by removing from the surface of the filter the layer of slimy sediment laden material (the "schmutzdecke"), along with some sand beneath it. The disadvantage of this procedure is a regular loss of filter sand, which is relatively

TABLE 2.—Description of Slow Sand Filter Tests.

Filter Run No.	Dates	Disinfection	Fiber Glass Mat	Flow Rate Gpd/Sq. Ft.[1]	Intake	Length of Run, Days	Water Filtered: Total Volume, Gallons	Water Filtered: Gal/Sq. Ft.
1	4/4/60 - 10/4/60	post-chlor	no	variable[2] max - 147	pipe[3] and barrel[4]	183	78,686	4,000
2	10/11/60 - 11/22/60	post-chlor	yes	variable[2] max - 74	pipe	42	12,600	643
3	11/28/60 - 3/27/61	post-chlor	no	min - 74 max - 92	pipe and barrel	119	50,140	2,560
4	3/27/61 - 7/24/61	pre-brom post-brom	no	min - 74 max - 103	barrel	119	58,800	3,000
5	7/24/61 - 1/25/62	post-brom	yes	min - 18 avg - 90 max - 191	barrel and surface[5]	185	127,898	6,530
6	1/25/62 - 7/10/62	post-brom	no	min - 57 avg - 147 max - 179	surface	166	169,680	8,650
7	7/10/62 - 4/30/63	pre-chlor	no	min - 57 avg - 139 max - 406	surface	287	282,246	14,400

[1]Gallons per day per square foot.
[2]Flow from filter was controlled by a float valve in clear well. As the clear well filled, the flow decreased.
[3]Pipe intake—600 feet of perforated 1¼" plastic pipe buried in the bottom of pond.
[4]Barrel intake—two 55-gallon steel drums filled with gravel.
[5]Surface intake—fiber glass strainer suspended 18 inches below surface.

expensive, and difficult to obtain. For these reasons a fiber glass mat was placed on top of the filter during runs 2 and 5, the purpose of which was to allow the schmutzdecke to develop on it, rather than on the sand. Cleaning could then be accomplished simply by replacing the fiber glass (an inexpensive item) with a new mat thereby saving the sand.

Test runs usually ended when the flow rate from the filter became inadequate. No sand was replaced until after run 6, when three inches were removed and five inches added.

(**Depth of Sand**) Twenty-four to forty-eight inches of sand are usually recommended for municipal slow sand filters. Publications presently available on the construction of farm pond slow sand filters recommend between 27 and 36 inches of sand with the further provision that from 6 to 12 inches of sand may be removed in the cleaning process before addition of sand is necessary.

The sampling ports 1, 2, 3, and 4 in the slow sand filter studied were 7, 19, 31, and 43 inches, respectively, below the surface of the sand (Figure 1). Water from port 5 passed through 46 inches of sand and 9 inches of gravel. The filter effluent was the same water as from port 5 except that it was usually taken at a slower flow rate and in five of the test runs the water was disinfected between port 5 and the effluent sampling point.

Turbidity and color results for each port are presented in Table 3. Considering the results of all runs, 57 percent of the turbidity and 42 percent of the color were removed by the approximate top 7 inches of sand. As influent turbidity increased, percentage removed also increased. However, larger average size of the sediment particles rather than turbidity concentration probably accounted for this increase. The high turbidity influents were usually encountered when the buried pipe and barrel inlets were in use. The suspended solids under these conditions usually settled easily indicating that the particles were of relatively large size. On the other hand the suspended solids from the surface intake settled slowly, indicating smaller-sized particles. The foot of sand beneath the top 7 inches reduced the turbidity and color only a slight amount, while the next foot of sand reduced the turbidity more than the previous foot (Table 3). These results are difficult to explain in light of the information obtained from an inspection of the filter which showed all the visible sediment in the top 8 inches, and the hydraulic data indicated a lower conductivity for the top 19 inches of sand, than for that 19 to 31 inches deep. A reasonable explanation for this inconsistency was not formulated.

TABLE 3.—Reduction of Turbidity and Color by Varying Depths of Sand in a Slow Sand Filter.

Run No.	Infl. Avg.	Port 1[1] Avg.	Port 1[1] % Red.	Port 2[2] Avg.	Port 2[2] % Red.	Port 3[3] Avg.	Port 3[3] % Red.	Port 4[4] Avg.	Port 4[4] % Red.	Port 5[5] Avg.	Port 5[5] % Red.	Effluent[6] Avg.	Effluent[6] % Red.
Turbidity (units)													
1	18.1	10.7	41	12.1	33	18.2	0	8.3	54	7.0	61	4.1	77
2	53.8	5.8	89	4.3	92	3.4	94	3.2	94	3.1	94	1.8	97
3	20.1	6.3	67	4.2	79	3.0	85	3.0	85	2.2	89	2.6	87
4	34.9	16	54	16.3	53	15	57	14.8	58	16.0	54	12.7	64
5	8.5	5.9	31	4.5	47	4.2	51	5.6	34	11.3	+33	6.2	27
6	23.3	15.1	35	14.1	39	7.7	67	7.1	70	6.3	73	5.3	77
7	16.8	16	5	9.5	44	7.9	53	7.5	55	6.1	64	5.1	70
Avg.	25.1	10.8	57	9.3	63	8.5	66	7.1	72	7.4	71	5.4	79
Apparent Color (units)													
1	44.2	30.8	30	39.5	11	38.9	12	38.1	14	36.4	17	28.3	36
2	93.3	15.8	83	14.1	85	14.9	84	14.6	84	10.8	88	6.6	93
3	27.5	2.7	90	2.1	92	1.5	95	1.3	95	0.9	97	1.5	95
4	42.6	37.7	12	35	18	36.7	14	32.5	24	28.5	33	28	34
5	32.3	31.3	3	27.6	15	31.5	3	37.2	+15	44.9	+39	41.9	+30
6	46.2	30	35	23.3	50	21	55	18.2	61	11.4	75	11.5	75
7	41.9	43.8	+5	25.8	38	20.9	50	18.8	55	16.7	60	17	59
Avg.	46.9	27.4	42	23.9	49	23.6	50	23.2	51	21.4	54	19.3	59

[1] Water filtered through approximately 7 inches of sand.
[2] Water filtered through approximately 19 inches of sand.
[3] Water filtered through approximately 31 inches of sand.
[4] Water filtered through approximately 43 inches of sand.
[5] Water filtered through approximately 46 inches of sand, plus 6 inches of gravel.
[6] Same as port 5 except water disinfected in runs 1, 2, 3, 5, 6 and in last part of run 4

TABLE 4.—Percentage of Samples Meeting Drinking Water Standards.

Run No.	Influent	Port 1	Port 2	Port 3	Port 4	Port 5	Effluent
				Turbidity[1]			
1	57	62	63	71	71	76	100
2	17	100	100	100	100	100	100
3	54	92	92	100	100	100	100
4	13	14	13	27	27	33	33
5	71	90	88	92	54	78	74
6	33	39	61	78	72	94	89
7	42	42	71	83	79	92	91
Average	41	63	70	79	72	82	84
				Apparent Color[1]			
1	38	38	32	43	48	48	52
2	0	67	67	67	67	84	84
3	78	100	100	100	100	100	100
4	23	46	46	38	46	46	62
5	29	29	50	54	50	54	52
6	38	38	62	78	83	100	93
7	29	22	46	57	67	75	74
Average	34	49	58	62	66	72	74

[1]Drinking Water Standard 1946; turbidity, 10; color, 20.

Of greater importance than the percent reduction in turbidity and color is the ability of a filter to produce a water which meets the specifications of the Public Health Service. The Drinking Water Standards of 1946 (13) were used to judge the performance of the filter. In only one test run was seven inches of sand able to reduce the turbidity and color to an acceptable concentration in 100 percent of the samples. As the water passed through greater depths of sand, more samples met the Standard, but during only three runs did the turbidity of all the effluent samples meet the Standards (Table 4 and Figures 2 and 3). The average effluent turbidity in all but one run met the Standard. The one exception occurred when the filter was being predisinfected (Run 4, Table 3).

Although the greatest amount of sediment was removed near the surface, the additional depth of sand improved the quality of water and often made the difference between an acceptable and an unacceptable effluent. From the standpoint of design, it would be advisable to provide the deepest bed of sand that was both feasible and economical.

(**Schmutzdecke**) The schmutzdecke development was more marked when the buried pipe intake was in use because of the higher organic content of the water. Large clumps of filamentous algae were observed on the surface of the filter on a number of occasions. The schmutzdecke had a distinct black color when the barrel and buried pipe intakes were employed in contrast to a grayish clay color when the surface intake was in use. Thickness of the schmutzdecke at the end of a test run varied from 1/32 to 1/8-inch with the thickest occurring when high organic loadings were applied. Borings showed that the majority of the sediment was in the schmutzdecke with small amounts in the sand down to 8 inches. These observations were consistent with the hydraulic data (see hydraulics section).

The fiber glass mat placed on the surface of the filter during runs 2 and 5 replaced the sand surface as the focal point of schmutzdecke formation. A 1/16-inch layer of clay, silt, algae, microorganisms, and organic matter formed on top of the fiber glass. A smaller amount of discoloration took place in the lower parts of the fiber glass. The sand under the fiber glass did not form a schmutzdecke or discolor to any perceptible degree. Additional studies indicated that the fiber glass alone was not able to produce an acceptable water and, therefore, a portion of the sediment must have been removed by the sand.

Limited tests with the fiber glass mat indicated (1) the fiber glass made cleaning the filter easier, (2) there was no need to remove or

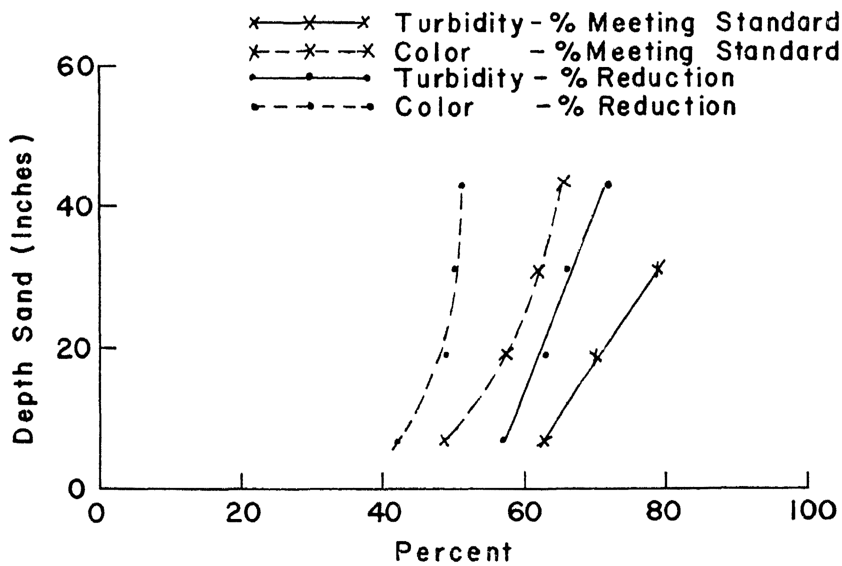

Fig 2.—Effect of filter sand depth on turbidity and color.

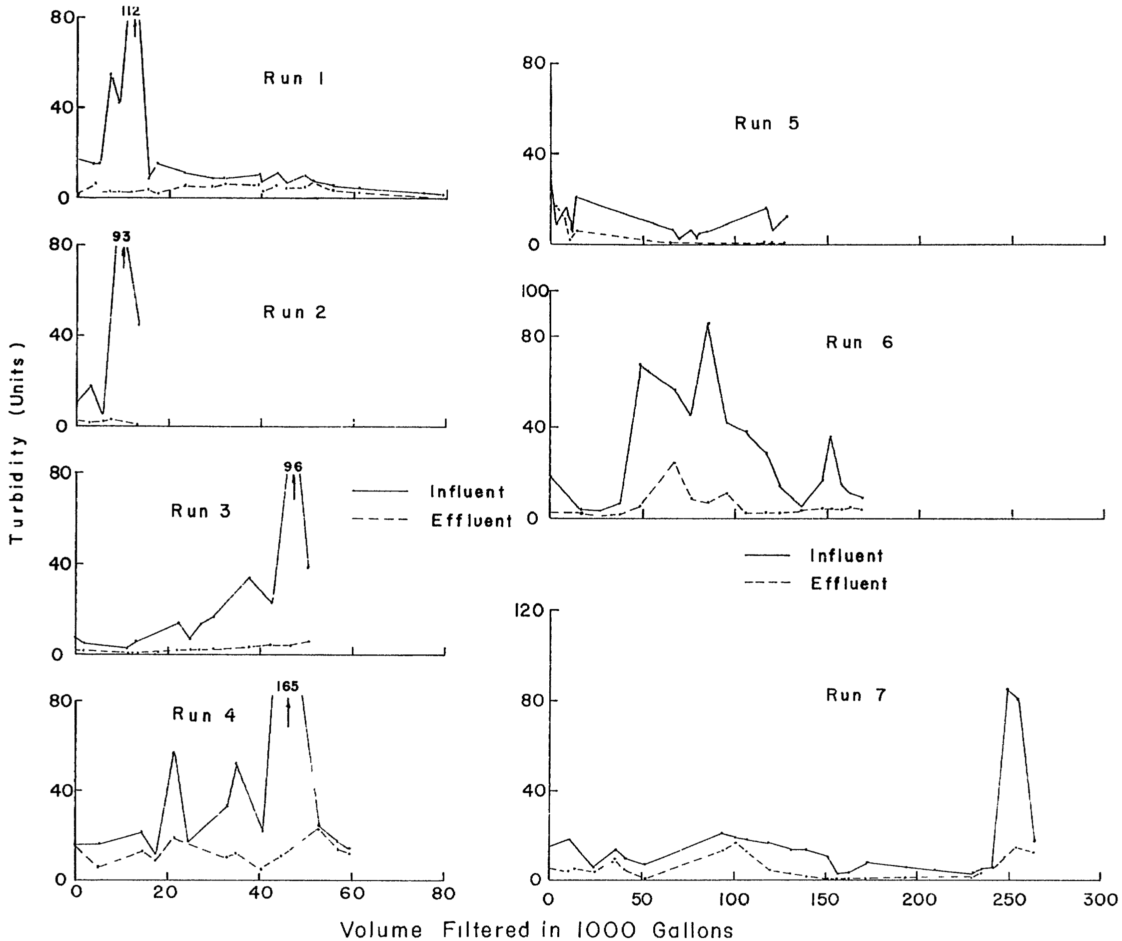

Fig. 3.—Turbidity of raw and finished water as a function of the volume filtered.

replace sand during cleaning operation although with prolonged use this might become necessary, (3) filter performance was not improved, and (4) length of filter runs were somewhat reduced.

(**Bacteria Removal**) The density of coliform bacteria in the influent and effluent samples was determined in all test runs. A number of investigators have reported that slow sand filters will greatly reduce coliform count, but not necessarily to an acceptable concentration. Similar results were recorded in this study (Table 5). The majority of the time the coliform bacteria population was reduced to less than 3/100 ml. However, approximately 45 percent of all filter effluent samples were still contaminated[4], therefore, the water would need further treatment to be safe for human consumption. On a few occasions the effluent density was greater than the influent density.

(**Predisinfection**) During the first 54 days of test run 4 the water was treated with Brom-Chlor-Dimethyl-Hydantoin (BCDH) prior to the filter and during all of run 7 the water was prechlorinated. The concentration of free available BCDH in the effluent from the chemical feeder was between 1 and 2 mg/l. The demand of the water reduced the concentration to 0.3 to 0.8 mg/1 by the time the water reached the the surface of the filter. After passage through 7 inches of sand, it was further reduced to about 0.2 mg/l. An additional foot of sand reduced the BCDH concentration to a trace (greater than 0 but less than 0.2 mg/l).

The influent water to the filter contained between 1.8 and 8.0 mg/l of chlorine during run 7. An attempt was made to maintain a free available chlorine residual of greater than 4 mg/l, but this proved rather difficult because of the varying chlorine demand of the water. However, in the majority of the cases this goal was achieved.

As shown in Figure 4, the top seven inches of sand reduced the chlorine residual markedly during the early part of the run and occasionally during the rest of the run. The lower layers of sand reduced the residual still more. The effluent water on a number of occasions contained only a trace of chlorine. The chlorine residuals of the filter effluent followed no set pattern varying from a trace to 4 mg/l. The low influent residual occurring at loadings between 240 thousand and 256 thousand gallons was a result of the high chlorine demand of the highly turbid water being filtered at that time.

Baumann, et al. (7), reported that prechlorination ahead of the slow sand filter resulted in longer filter runs and better filtration. The length of run 7 (prechlorination) far exceeded the other runs in both

[4]An MPN of less than 3.0 coliforms per ml was considered to represent the absence of coliforms.

TABLE 5.—Coliform Bacteria Reduction by Slow Sand Filter.

Test Run	Influent Density, MPN/100ml			Effluent Density, MPN/100ml			Percent Reduction[1]	Percent Effluent Samples Contaminated
	Maximum	Minimum	Median	Maximum	Minimum	Median		
1	1,500	<3	43	2,400	<3	14.5	66	71
2	1,500	23	93	43	<3	23	75	80
3	93	7.2	23	23	<3	<3	100	18
4[2]	1,100	<3	93	93	<3	3.6	96	54[2]
5	1,100	3.6	17	9.1	<3	<3	100	45
6	460	<3	9.1	15	<3	<3	100	44
7[3]	1,100	<3	23	$>1,100$	<3	<3	100	30
Median of Medians	1,100	<3	23	43	<3	<3	100	45

[1]Calculations based upon median values of influent and effluent densities.

[2]First 54 days of test, water was predisinfected. During this period median effluent was 3 and only 1 of 6 samples was contaminated Remainder of run water was post disinfected and median effluent was 23 and all samples were contaminated.

[3]Water prechlorinated.

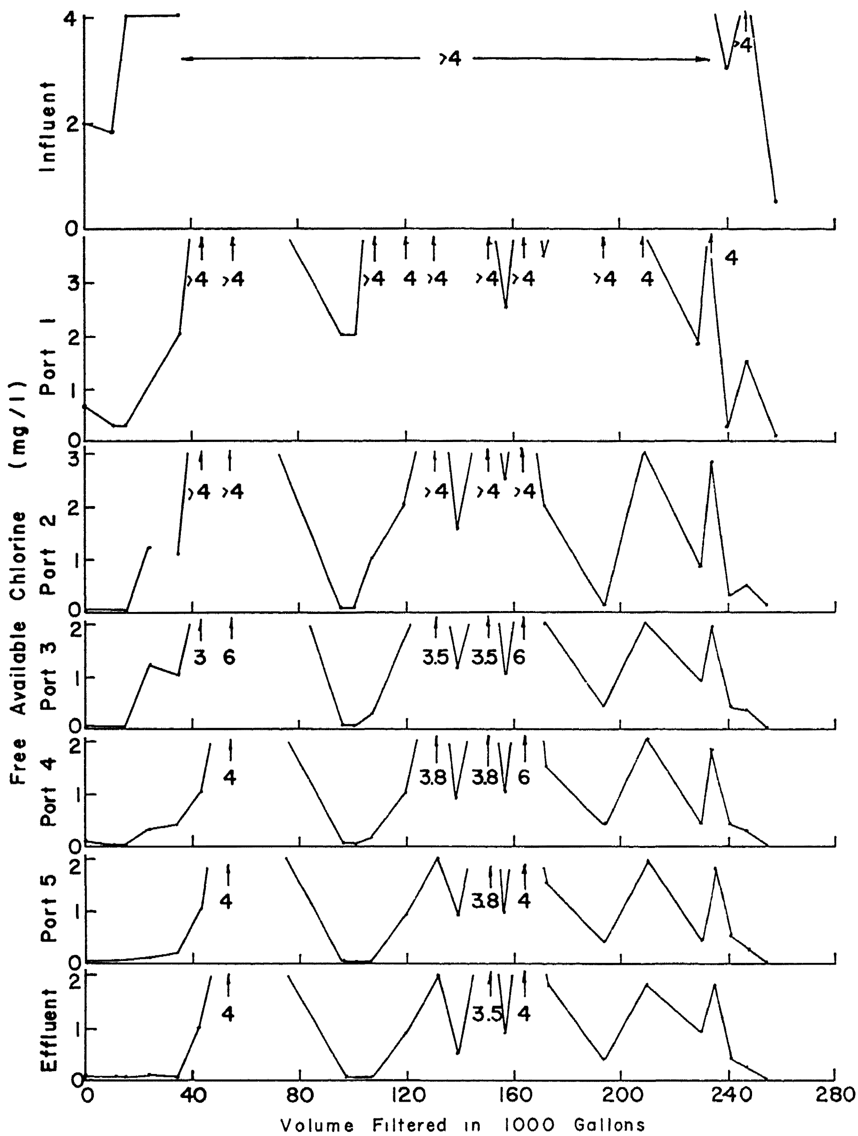

Fig. 4.—Free available chlorine residuals for the prechlorinated slow sand filter - Run No. 7.

volume of water filtered and days of operation, verifying their results in respect to filter run length. However, there was no significant change in efficiency of removal of turbidity or apparent color. During the critical period of February, March, and April, when the turbidity

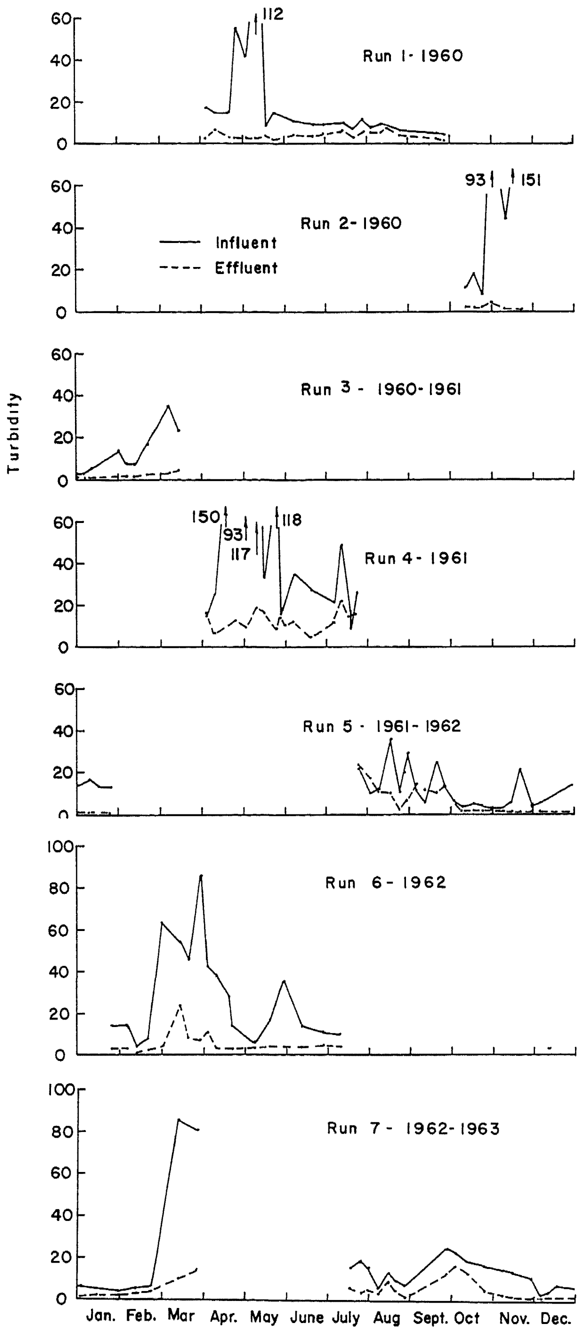

Fig. 5.—Monthly variation in turbidity of raw and treated water.

was at its maximum and was composed of very fine particles, the filter did not produce satisfactory water. This was also true in the case of water that was chlorinated after the filter, but a comparison of runs 6 and 7 (Figure 5), which had similar raw water showed that the zoogloeal masses on the filter whose effluent was chlorinated aided in the removal of this fine turbidity.

The smallest percentage reduction of turbidity and color by the top seven inches of sand occurred when the water was prechlorinated (Table 4). This would indicate that filtration took place deeper in the bed during prechlorination than under post-chlorination. There was also a slight increase in color below seven inches of sand which was probably a result of the oxidation of organic matter by the chlorine.

When the influent water was predisinfected with BCDH some of the poorest results were obtained. In a majority of cases the turbidity concentration was not reduced to an acceptable level. However, during this run the influent turbidity was among the highest values recorded during the study.

During four of the runs an analysis was made to determine the levels of population of groups of bacteria other than coliform, such as (1) total bacteria, (2) thermoduric bacteria, (3) thermophilic bacteria, (4) psychrophilic bacteria, and (5) enterococci.

When the water was being post-disinfected samples were not taken immediately after the filter, but after the water had been disinfected. This water had very short disinfectant-water contact time, *i.e.*, less than one second. Data from these bacteriological analyses are presented in Table 6.

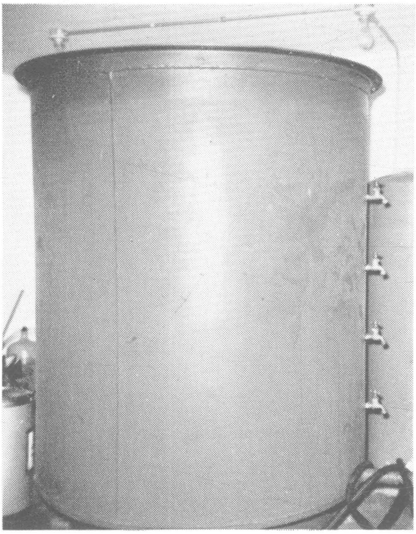

Fig. 6.—Experimental slow sand filter.

TABLE 6.—Bacterial Removal by Slow Sand Filter in Conjunction with Disinfection.

Run No.[1]	Raw Water			Filter Influent			Filter Effluent		
	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median
					Total Bacterial Count (SPC/ml)				
4a	120	19	65				230	70	150
4b	5,400	300	520		same as raw water		2,400	80	100
5	3,200	30	1250		same as raw water		250	<10	120
6	24,000	30	245		same as raw water		1,300	10	50
7	1,100	60	105	250	10	80	1,100	10	10
					Thermoduric (per ml)				
4a	36	22	29						
4b	400	5	22				81	7	18
5	>3,000	7	11.5				130	4	8
6	50	7	26				34	1	18
7	33	6	17.5	27	4	14.5	390	<1	3
					Thermophiles (per ml)				
4a	10	2	4						
4b	3	1	3				>3,000	1	2
5	1	<1	<1				3	<1	<1
6	54	1	10.5				13	<1	4
7	25	1	2	19	<1	2	4	<1	<1

[1]Test runs 4b, 5, 6, — post disinfected with BCDH, contact time approximately 1 second.
Test run 4a — predisinfected with BCDH.
Test run 7 — predisinfected with chlorine.

TABLE 6. (Continued)—Bacterial Removal by Slow Sand Filter in Conjunction with Disinfection.

Run No.[1]	Raw Water			Filter Influent			Filter Effluent		
	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median
				Psychrophiles (per ml)					
4a	115	26	26						
4b	250	<1	17				8,000	<1	58
5	1	<1	<1				30	<1	<1
6	32	<1	5				103	<1	<1
7	22	<1	<1	3	<1	1	1,365	<1	<1
				Enterococci (MPN/100 ml)					
4a	75	<1.8	<1.8						
4b	110	<1.8	4.5				9.2	<1 8	2.2
5	26	<1.8	18.5				11	<1.8	6.4
6	56	<1.8	2.9				9.1	<3	<3
7	9.1	<3	<3	3	<3	<3	3.6	<3	<3
				Coliform (MPN/100 ml)					
4a	270	15	22		3		9.1	<3	<3
4b	11,000	3	43				43	<3	3.6
5	39	3.6	3.6				3.6	<3	<3
6	43	<3	3.6				9.1	<3	<3
7	43	<3	9.1	9.1	<3	<3	3	<3	<3

[1]Test run 4b, 5, 6, — post disinfected with BCDH, contact time approximately 1 second.
Test run 4a — predisinfected with BCDH.
Test run 7 — predisinfected with chlorine.

In general, the population of all the bacterial groups studied was reduced by treatment. However, in individual sets of samples the population of a particular group sometimes increased rather than decreased. The enterococci and coliform densities were almost always reduced and in the majority of the cases, to less than 3/100 ml.

Considering the median values for each bacterial group, better results were obtained when the water was prechlorinated. This would be expected because of the greater disinfectant-water contact time under these conditions. The average effluent water was bacteriologically acceptable where prechlorination was practiced, but with post-disinfection greater contact time and/or chlorine concentration is required to reduce enterococci, coliform, and total bacterial populations to a suitable concentration.

Although no specific data were obtained, the results for post-disinfection indicate that the sand filter alone did not reduce the bacteria density to any great extent and that an acceptable bacterial population is not obtained by filtration alone.

(**Flow Rate**) Flow rates of 35 to 100 gallons per minute per square foot surface area are commonly recommended for slow sand filters. During test runs 4 through 7 determinations were made to study the effect of flow rate on filter performance. Tests were conducted on six different days during run 6. The filter was given 1 to 2 hours to stabilize after each change in flow rate. Then samples were analyzed for turbidity and color. The adequacy of this stabilization period was questionable. Therefore in run 7 the filter was allowed to stablize one week at a specified flow. In test runs 4, 5, 6 and the last part of 7 the flow rate was kept fairly constant to study the long time effect of flow rate on filter performance.

Results of the short duration (1-2 hours) revealed that at flow rates of 14.7 to 180 gallons per day per square foot (even as high as 340 gpd/sq. ft. in one case) that there was no significant difference in the quality of the effluent water. Similar results were obtained when the filter operated one week at a specified flow. The average flows for tests runs 4, 5, 6, and 7 were 74, 90, 147, and 100 gpd/sq. ft., respectively. The average effluent from these runs was essentially the same except for run 4 in which the turbidity was twice as high. This increase was due to the predisinfection of the water as explained earlier (Table 3).

(**Hydraulics**) Darcy's formula was used to calculate the conductivity of successive layers of filter media. Manometers were attached to each sample port and data from these pressure measurements used to calculate head loss at a given flow.

TABLE 7.—Conductivity of Successive Layers of Sand and Gravel in a Dirty Slow Sand Filter.*

Depth of Layer Below Surface (inches)	Layer Material	Hydraulic Conductivity (ft/min)
0 to 7	Schmutzdecke plus sand	.03
7 to 19	Sand	.05
19 to 31	Sand	.45
31 to 43	Sand	.29
43 to 55	Sand-3″, gravel 9′	.30
Entire Filter	Sand-46″, gravel 9″	.10

*Filter had been in operation for nine months.

Conductivity would be expected to be approximately the same at all depths of a clean sand filter. But as sediment collects in the pores of the filter the conductivity would be expected to decrease. Therefore, the layers of sand that had the smallest conductivity would contain the largest amount of sediment. Table 7 summarizes data from five tests made after the filter had been in operation nine months (run 7). From this information it can be concluded that the greatest amount of sediment was removed in the top 7 inches of sand as indicated by the low conductivity. The following foot of sand also collected sediment. These results are in agreement with the conclusions of Baumann, *et al.* (7) who found penetration one foot below the surface in a post-chlorinated slow sand filter and only one inch in a prechlorinated slow sand filter. Although this filter was being prechlorinated during the time these tests were made, it is likely that some of the sediment at lower levels was residual from earlier tests. However, in light of the results showing less turbidity removal by the top 7 inches during prechlorination, it would seem that a deeper penetration of sediment occurred than reported by Baumann.

At the time the above tests for conductivity were made the total head loss through the filter was only six inches at a flow rate of 103 gallons per day per square foot. Toward the end of most of the runs the head loss became so great (conductivity very small) that no flow occurred at port 1 and sometimes at port 2. Generally there was always some flow at the other ports except for two cases where there was no flow from any of the ports.

(**Seasonal Variation**) As illustrated in Figure 5, there was a seasonal variation in the physical quality of both the raw and treated water.

Under normal operating conditions (surface intake and post-chlorination) the most troublesome and critical period was during high runoff in early spring. At that time turbidity was at or near its maximum and difficulty was experienced in producing acceptable water. Apparent color at that time of year was composed primarily of suspended matter (turbidity) and was not reduced sufficiently. The turbidity in raw water during this period settled very slowly indicating that it was composed of very small particles. From all indications this was the source of difficulty.

The implication of this finding was that in order to produce a water supply that met the Drinking Water Standard year around, some type of treatment in addition to filtration would be necessary during the spring. This treatment might be a secondary or polishing filter capable of removing very fine particles, or prefiltration treatment such as flocculation.

Pressurized Rapid Sand Filter The type of sand filter most commonly found in rural homes is the pressurized rapid sand filter, chiefly because of its availability on the consumer market. This filter normally is made with the same type tank as a water softener but with the ion exchange media replaced by filter sand. The pressurized rapid sand filter was tested (1) in combination with secondary filters (discussed in next section), (2) with flocculating agents added prior to filtration, and (3) after modifying normal filter operation.

The pressurized rapid sand filter (OAES-1)[5] was a 16-inch water conditioner tank filled with sand (Figure 7) and equipped with a manual backwash mechanism. Four test runs were made with this filter. The components of the water treatment system for each run are indicated below.

Run 1: Gravel filled barrel intake in pond, pump, chlorinator, 120-gallon pressure tank, and rapid sand filter.

Run 2: Perforated plastic collector pipe buried in bottom of pond, pump, chlorinator, 42-gallon tank filled with coarse gravel used for chlorine-water contact, 120-gallon pressure tank and rapid sand filter.

Run 3: Perforated plastic collector pipe intake, pump, 120-gallon pressure tank, chlorinator, 42-gallon gravel tank, and rapid sand filter.

Run 4: Gravel filled barrel intake in pond, pump, chlorinator, 42-gallon pressure tank, 42-gallon gravel tank, and rapid sand filter.

[5]The OAES symbol preceding numbers designating pressurized rapid sand filters i.e. OAES-I etc refers to models developed at the Ohio Agricultural Experiment Station, Wooster, Ohio.

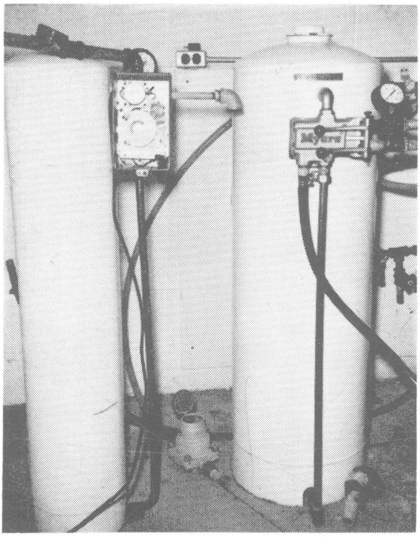

Fig. 7.—Pressurized rapid sand filter. Left unit has controls for automatic backwash; right unit for manual backwash.

The plastic collector pipe was used in runs 2 and 3 because a pooper quality of water was furnished by this intake than by the gravel filled barrel. This was done in order to test the filter performance under conditions of high turbidity and color. During runs 1 and 2 a sand with an effective size of 0.4 mm and uniformity coefficient of 1.85 was employed. After run 2, the sand was removed from the filter and inspected. Even though the filter had been frequently backwashed at a rate of 8-10 gpm the sand contained a large amount of sediment indicating the backwashing operation was not effective in cleaning the sand. Normally, the filter was backwashed every 7-14 days, however, during the last two months of run 1 the filter was not backwashed with no resultant reduction or increase in the filter efficiency. The sand was changed for runs 3 and 4. The effective size of this sand was 0.56 mm and the uniformity coefficient 1.5 Maximum flow rate for the four runs was 3.57 gallons per minute per square foot.

Results of the four runs are tabulated in Table 8 and illustrated in Figure 8. Influent turbidity and color were relatively low for runs 1 and 4. The turbidity was reduced 37 and 36 percent, respectively during these two runs. Runs 2 and 3 had much higher influent turbidities. Under these higher turbidities, greater percentage reductions were recorded. Influent color was also greater in runs 2 and 3 as a result of the higher turbidity. During run 2 the color was reduced 50 percent, and 22 percent of the samples met the Standard for color. Run 3 showed a reduction of 29 percent and only one of the samples

TABLE 8.—Pressurized Rapid Sand Filter Test Data.

No. Run	Average Influent Turbidity (units)	Percent Reduction in Turbidity	Percent Samples Meeting Standard[1]	Average Influent Apparent Color (units)	Percent Reduction Apparent Color	Percent Samples Meeting Standard[2]	Average Influent Chlorine (mg/l)	Percent Reduction Chlorine	Flow Rate gpm/sq. ft.	Total Flow of Run 1000 Gallon
				(Manual Backwash - OAES I)						
1	8	37	96	24	42	84	0.8	75	2.8	99.6
2	73	59	13	101	50	22	—	—	1.7	56.2
3	47	47	14	123	29	0	0.19	16	1.9	2.6
4	11	36	80	27	4	40	0.66	47	1.25	21.7
				(Automatic Backwash - OAES II)						
5	75	15	0	120	28	0	1.4	36	3.9	39.2
6	12	12	62	26	19	62	0.65	31	4.1	37.7

[1]Maximum Turbidity according to the 1946 Drinking Water Standard, 10 units.
[2]Maximum Color according to the 1946 Drinking Water Standard, 20 units.

met the drinking water standard for color. The reduction in apparent color was probably a result of the removal of turbidity and not the removal of true color.

Average influent residual chlorine for runs 1, 3, and 4 was 0.8, 0.19, and 0.66 mg/l, respectively. For runs 1 and 4, which had the higher chlorine residuals, reduction of 75 percent (run 1) and 47 percent (run 2) were recorded. The chlorine was reduced only 16 percent by the filter during run 3. It appeared that the chlorine combined with the organic matter in the filter.

One solution proposed for the problem of low filtration efficiency for pressurized rapid sand filters was more frequent and better backwashing of the filter. As mentioned earlier, the backwashing process of the OAES-1 was inadequate. An automatic backwashing filter (OAES-2) was, therefore tested. Two test runs were made with a 10-inch diameter filter containing a sand with an effective size of 0.56 mm and a uniformity coefficient of 1.5. The filter was backwashed nightly for 15 minutes. Maximum flow rate was 5.5 gallons per minute per square foot and the average flow rate 4 gallons per minute per square foot. The water treatment systems for runs 5 and 6 were the same as for runs 2 and 4 , respectively. The two filters were operated in parallel to compare their efficiency.

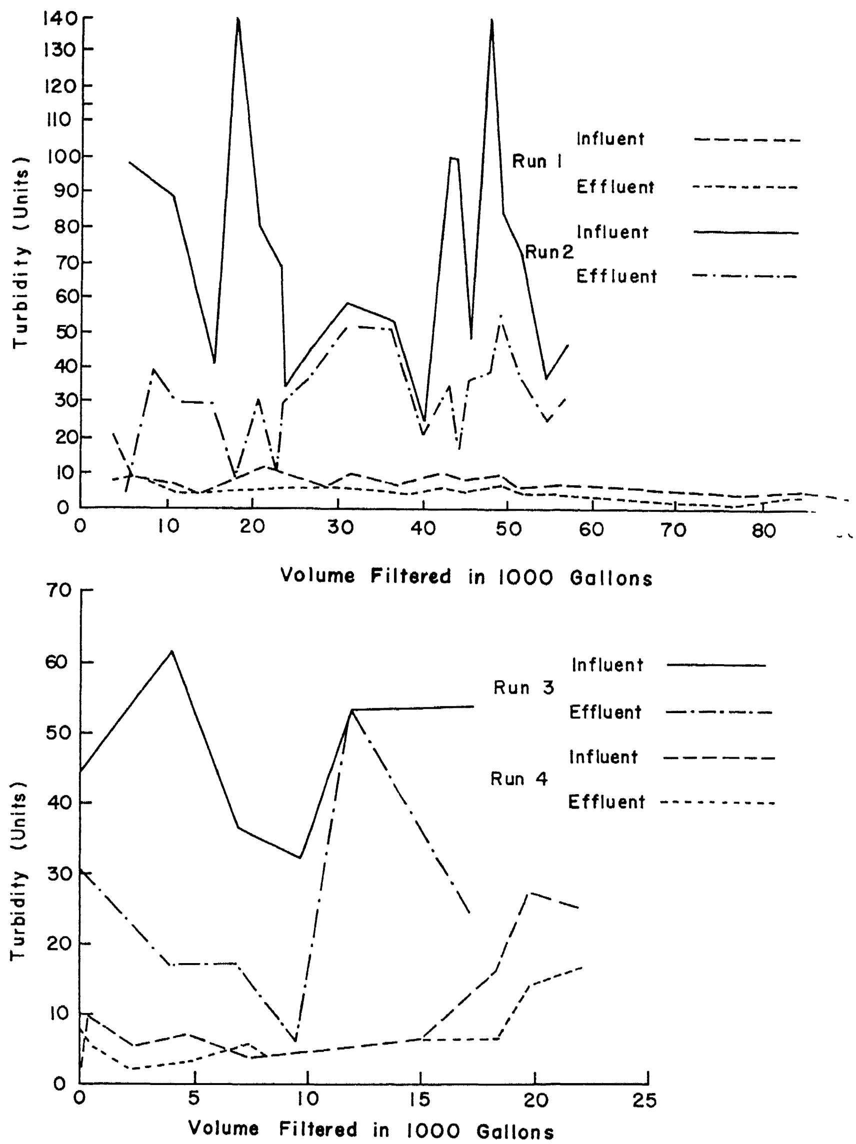

Fig. 8.—Filtration with a pressurized rapid sand filter OAES 1 (manual backwash).

The influent turbidity and color for run 5 was relatively high—averaging 75 and 120, respectively (Table 8 and Figure 9). Reductions in turbidity of 15 percent and color of 23 percent were recorded. During run 6 the influent turbidity averaged 12 units, and color 26 units.

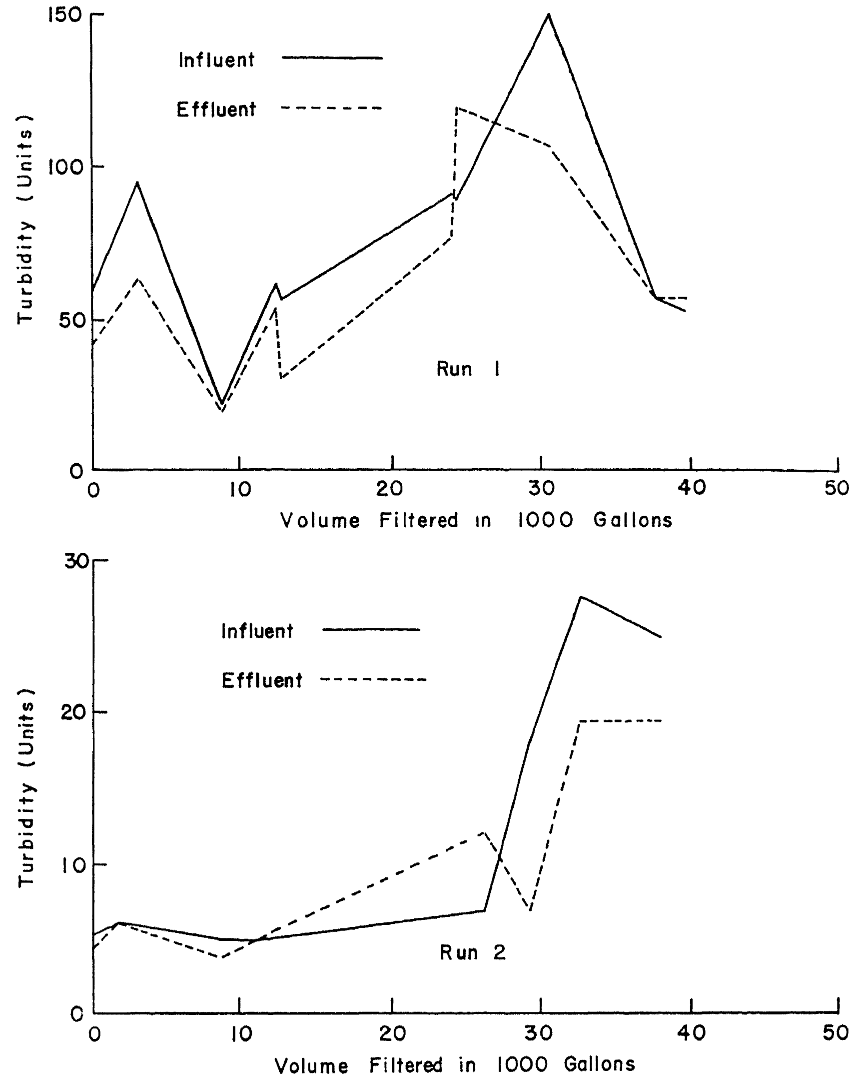

Fig. 9.—Filtration with a pressurized rapid sand filter OAES 2 (automatic backwash).

Turbidity was reduced 12 percent and color 19 percent. The chlorine residual during this run was reduced 31 percent from an average of 0.65 mg/l.

A comparison of daily versus weekly backwashing for high turbidity conditions can be made by studying run 5 for the automatic backwash filter and run 2 for the manual backwash filter. The filter that was backwashed daily reduced the turbidity 15 percent while the weekly backwashed filter reduced the turbidity 59 percent. Similar results can be seen if run 6 is compared to run 4. These runs took place under low turbidity conditions. The weekly backwashed filter produced the greatest reduction in turbidity (36 percent) and the daily backwash filter only 12 percent. More frequent backwashing decreased filter efficiency. As shown in Table 8, the flow rate was greater for the automatic backwashed filter and may account partially for its poorer performance.

However, in an evaluation of the effect of flow rate on filter performance, it was found that for a range normally used in the home (1 gpm to 10 gpm) the quality of effluent water did not change significantly. In cases where the filtration rate was increased after the filter had been operated at a low flow rate turbidity was washed out in the effluent.

Results for the pressurized rapid sand filter systems are summarized in Table 8. Pressurized sand filters reduced turbidity from 12 to 59 percent and apparent color from 4 to 50 percent. Percentage reduction, however, is not as important a consideration as is the quality of the effluent water. In general the effluent water quality was poor. When the influent turbidity was greater than 10 units, the best filter run showed only 80 percent of its samples meeting the Drinking Water Standards. Most of the filters produced water that met the Standards 60 percent of the time or less. Similar results were found for color. Such low efficiency indicates that the pressurized rapid sand filters tested were not suitable for filtering raw pond water.

Pressurized rapid sand filters in many cases acted as good dechlorinators. This effect may be an advantage or disadvantage. Where chlorine-water contact time is at a minimum, reducing the chlorine residual is a detriment. In cases where bacteria kill has been assured, a separate dechlorinator other than the rapid sand filter may not be needed.

(**Flocculation—Pressurized Rapid Sand Filtration**) The small size of the turbidity particle (less than 5 microns) was the major reason for poor filter efficiency. For this reason investigations were initiated to study methods of increasing particle size. Since flocculation is employed in the municipal water treatment plants for this purpose, it was felt that this process might be applicable to the individual water treatment system. Unlike the municipal system where the floc is settled out in settling tanks, it was decided to filter the floc with a pressurized rapid sand filter.

Alum was the flocculating agent selected because of its reasonable cost and availability. A modified jar test was used to determine the amount of alum needed for good flocculation. Since a pressurized rapid sand filter system does not provide for rapid mix followed by slow mix as in conventional treatment, but only rapid mix achieved in pipelines and the pressure tank, the jar test was altered to include only a five minute rapid mix (155 rpm) followed by settling. Effectiveness of dosage was rated on the basis of floc size and the settling rate. This test left much to be desired as a simulation of true conditions because the mixing probably exceeded that in the filter system. However, it gave information as to the relative effectiveness of the alum dosage.

Untreated raw water was collected for jar studies. These tests were made for more than a year to determine if there was seasonal variation in the amount of alum needed. Tests were conducted at room temperature. Alum dosages between 10 and 70 ppm were evaluated. In most all cases the 50 ppm dosage produced the fastest settling floc, while 50 to 70 ppm produced the largest floc particles. From this information the 50 ppm dosage was chosen for field tests. Jar tests also showed that pH would be lowered from 7.5 to less than 6.8 by this alum dosage.

Investigations were also made into the use of coagulating aids either by themselves or in combination with alum to improve flocculation.

The coagulating aids tested were Separan NP10, NP20, and AP30; and Hagon No. 952. Dosages ranged between 0.5 and 6 ppm. The coagulant aid was added just after the alum and before mixing. Laboratory studies showed no advantage in using these materials either alone or in conjunction with alum, thus no field studies were conducted with these materials.

The field installation employed in the flocculation studies was similar to that in run 4, OAES-I for the manual backwashed filter except that a diaphragm chemical feeder pump was installed in the system to feed the alum between the water pump and pressure tank. The diaphragm pump which operated at a constant feed rate stopped and started with the water pump.

The diaphragm pump and the alum solution feeder were adjusted to obtain a concentration of 50 ppm in the water when the water pump was operating at maximum capacity. At flows less than maximum, greater amounts of alum were obtained. The actual alum concentration in the water was not determined analytically. At times during these tests the alum dosage was varied in order to evaluate this factor under actual conditions.

Data from the three test runs are summarized in Table 9 and illustrated in Figure 10. The average effluent turbidity and color for runs 1 and 2 were acceptable, but not so in run 3. Considering individual samples, run 1 showed the best results in that 89 percent of the samples met the 1946 Standards for turbidity and color. Run 2 produced a higher percentage of samples (90 percent) meeting the turbidity Standard, but a lower percentage (60 percent) meeting the color Standard. The poorest results were recorded for run 3 in which only 57 percent and 43 percent, respectively, met the Standard for turbidity and color.

These results were better than those obtained with pressure sand filtration alone. The majority of unacceptable samples could be traced to insufficient alum dosages resulting from alum feeding problems. The first chemical feeder used had a number of stoppages due to plugged check valves and air locks. Placing the intake of the feeder pump near the surface of the alum solution by means of a float alleviated most of the plugging problems. When this chemical pump was removed from the system a large deposit of alum sludge was found in the water line adjacent to the point of alum application.

The second chemical pump developed a leak around the diaphragm shortly after being placed in use. This leak was never completely eliminated. Leakage from the feeder returned to the alum reservoir, and alum usage was only about 14 ppm during most of run 3. This compared to 39 ppm for run 2. Accurate measurements of alum usage during run 1 were not made.

On several occasions during run 1 the effect of flow rate on efficiency of the system was measured. Results of a typical test are shown in Figure 11. It can be seen that a different breakoff point occurred, *i.e.*, the point below which the alum dosage was insufficient for good turbidity and color removal. This breakoff point in the treatment system was higher than that indicated by the jar tests, probably because of less complete mixing.

Alum feeding ahead of a pressure rapid sand filter showed promise of improving performance of this type of filter. Further research on alum feeding techniques, mixing procedures and overall operation are needed if this method is to be acceptable for private water systems.

TABLE 9.—Flocculation-Pressure Rapid Sand Filter Data.

Run No.	Dates	Turbidity (units) Influent	Turbidity (units) Effluent	Apparent Color (units) Influent	Apparent Color (units) Effluent	Coliform Bacteria[3] Influent	Coliform Bacteria[3] Effluent	Total Gallons Filtered	Average Flow Rate GPM
1	2/6 - 7/17/62	29.7	5.4	52.6	9.5	—[1]	—[2]	49,750	1.2
2	10/3 - 1/3/63	13.2	5.3	35.5	19	9.1	3.6	52,684	2.6
3	1/3 - 4/16/63	33.6	13.0	75.0	28.6	23	3.6	33,616	2.9

[1]Water prechlorinated.

[2]Temperature range: run 1, 39 to 80°F; run 2, 42 to 79°F; run 3, 41 to 53°F.

[3]MPN/100 ml.

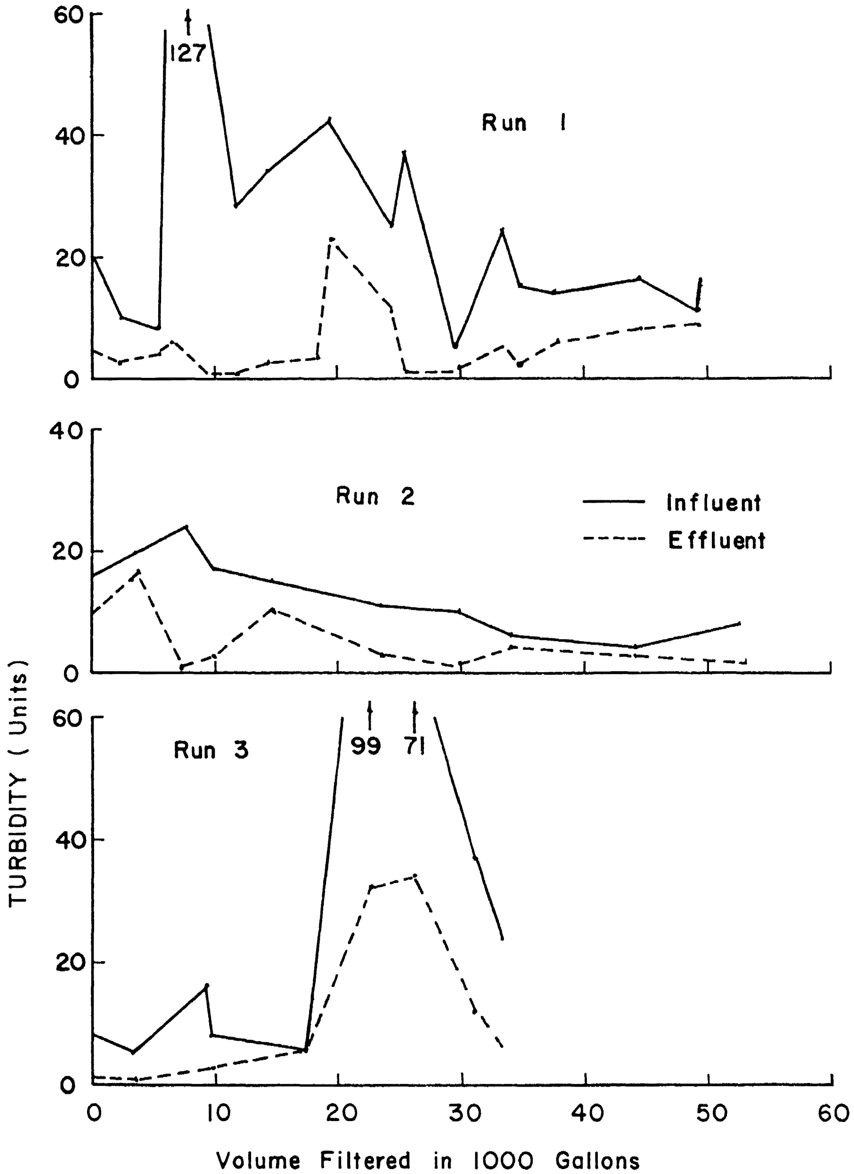

Fig. 10.—Filtration with a pressurized rapid sand filter (with flocculation).

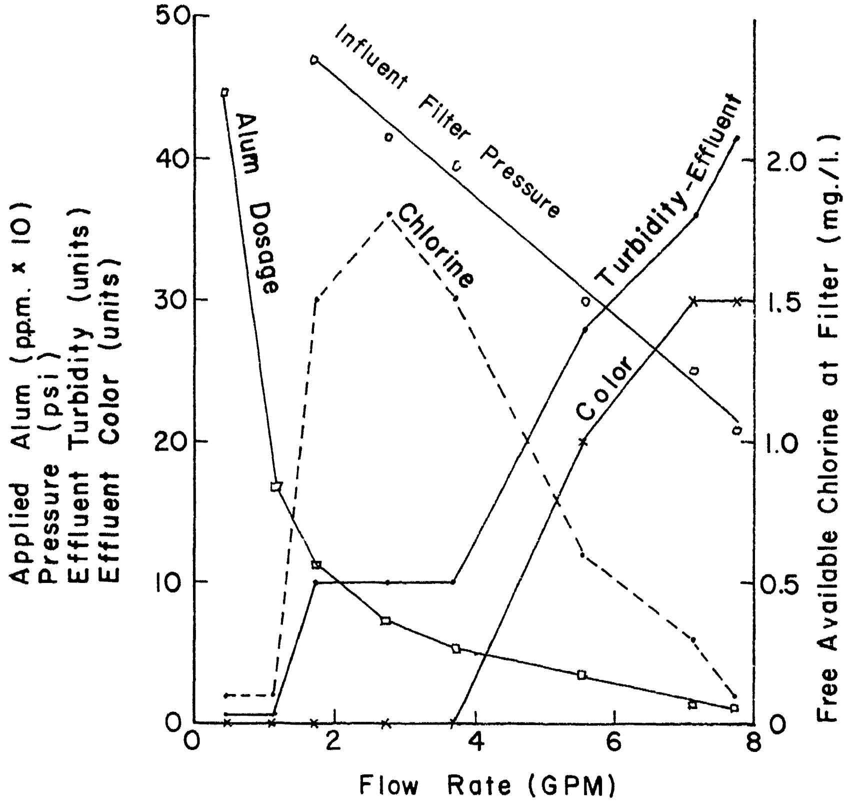

Fig. 11.—Effect of flow rate on flocculation with a pressurized rapid sand filter. Raw water quality: Turbidity - 56, Color - 40, pH - 7.5, Effluent pH <6.8. (Floc present in effluent samples at flow rates greater than 4 gpm).

Secondary Filters

Previous work has indicated that primary sand filters alone do not always produce water of acceptable quality and cannot remove certain substances, such as true color and odor. A secondary filter may be needed under these conditions.

Two types of secondary filters were investigated. These were (1) the cartridge filter and (2) the precoated carbon filter. The cartridge filters appeared to be suitable for the removal of turbidity and apparent color due to suspended solids, while precoated carbon filters reduced chlorine, true color, and odor as well as suspended solids.

Cartridge Filter As defined here, a cartridge filter is one in which the filter unit (usually constructed of cellulose acetate, ceramic material or felt) may be removed and discarded upon becoming clogged.

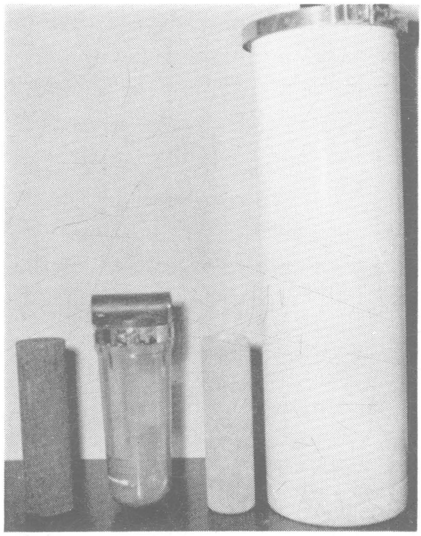

Fig. 12.—Secondary filters, (left to right) felt cartridge, cartridge holder, cellulose cartridge, precoated carbon filter.

Cartridge filters of various sizes are on the market (see Figure 12). The one cartridge size is for removing turbidity from household water supplies, while multiple cartridge units are suitable for swimming pools and highly turbid water. A one cartridge filter with a cellulose acetate cartridge and a felt cartridge was tested. According to the manufacturer these cartridges had pore sizes of 5 and 25 microns, respectively. Nine test runs were made on the cellulose filter in the laboratory. Three to four samples were taken during each test run. A total of 542 gallons of water was filtered. The reduction in turbidity varied from 33 to 72 percent, with an average reduction of 55.7 percent. The filter became more effective after being in use a short time. This was probably due to a buildup of sediment on the filter which resulted in the pore size being reduced. After 184 gallons had been filtered, the turbidity of the effluent met the Drinking Water Standard (10 units). Figure 13 shows the influent and effluent turbidities plotted against total gallons filtered.

The results of laboratoy tests indicated that the filter might have some application in filtration of pond water, but the small size of the unit prohibited its use as a primary filter. The unit was later installed in an experimental system, as a polishing filter. This system was composed of a chlorinator, 120 gallon pressure tank, pressurized rapid sand filter, and cartridge filter.

Three filter runs were made under field conditions. In two of these runs a cellulose fiber filter was used, and in the other a felt filter.

Figure 13 shows the variation in the influent and effluent turbidities. The influent turbidity, with one exception was below 10 units of turbidity. Thirty-three percent of the samples had a higher turbidity in the effluent than in the influent, while 44 percent of the samples showed no change in turbidity.

The influent color for the three test runs varied between 0 and 30 with an average of 15 units. The overall reduction in color was 3 percent. Fifty-six percent of the samples showed no decrease in color and 15 percent showed an increase. The cartridge filters had no effect on odor.

When the cartridge filter was used as a secondary filter following a pressurized rapid sand filter, and the influent water had a turbidity of less than 10 units, the filter removed little if any turbidity or color. The poor efficiency of this type of filter can be attributed partly to the small size of particles of suspended matter. The majority of the turbidity appears to be in the clay range of less than 2 microns and the colloidal range of less than one micron. On the basis of three tests the cartridge-type filter does not seem to be suitable for purification of pond water. Laudenschlager (16) obtained similar results with a 5-micron cartridge filter. He also found that filtration could be improved if the cartridge was precoated with diatomaceous earth.

Precoated Carbon Filters A precoated filter is one in which a thin layer of filter aid is supported on a septum. Diatomaceous earth filters are usually of this type. The filter aid removes suspended solids. A precoated carbon filter is a special type in which "activated carbon" is mixed with the filter aid. The carbon has a high absorptive capacity for color, odor, and chlorine. This type of filter comes in a number of sizes ranging from one to 20 square feet of surface area. Smaller units are used primarily to dechlorinate and "polish" water while larger units find application as filters of iron precipitates and other suspended matter as well as chlorine, color, and odor removal. The larger unit (20 sq. ft., OAES-20) was studied because previous experience had shown that the smaller units had a short life. The original unit was returned to the manufacturer and was replaced by a similar unit (OAES-20A). The element in OAES-20 was found by the manufacturer to have been pierced in two locations with wire that made up the drainage section of the element. This could have resulted in some leakage of turbidity into the effluent. The OAES-20 filter was used after a pressurized rapid sand filter in runs 1, 3, 4, and 5, and after a slow sand filter in run 2. During run 5 alum was fed to the water ahead of the pressurized rapid sand filter. Operational details for run 6 when OAES-20A

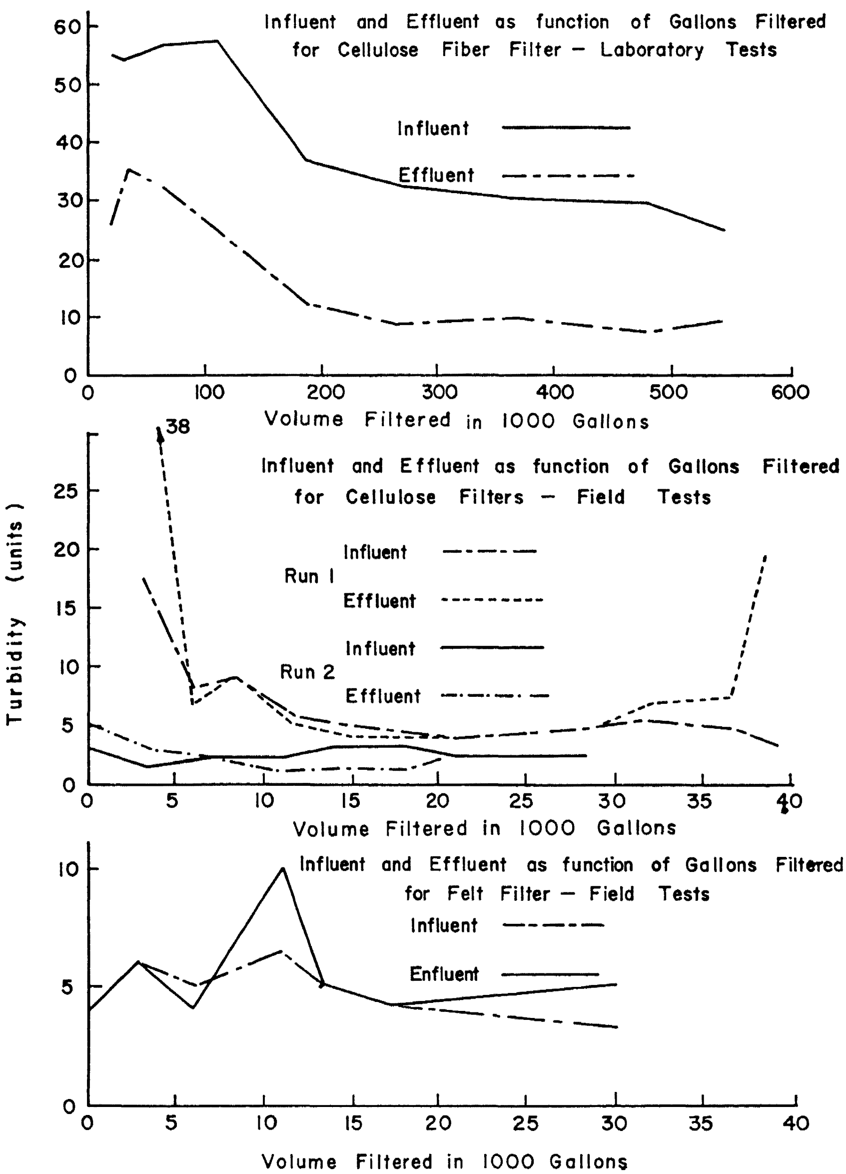

Fig. 13.—Filtration with a cartridge-type filter.

was in use were similar to run 5. During runs 7 and 8, OAES-20A was the last unit in a treatment system composed of a pump, alum feeder, pressurized rapid sand filter, brominator, 42-gallon gravel filled tank, and precoated carbon filter.

A filter run was considered complete when the flow rate from the filter became inadequate. At that time the filter was disassembled and the septum and its cake inspected. After inspection the septum was cleaned by washing with clean water and scrubbing with a brush. The unit was then recharged as recommended by the manufacturer.

The results of the eight test runs are shown in Table 10 and in Figure 14. Results of test run 1 were not in agreement with the remaining runs. The reasons for this poor performance were never ascertained, but may have been due to the holes found in the septum. All other tests showed that this filter was effective in reducing turbidity, apparent color, and chlorine. Chlorine appeared to be more easily removed than brom-chlor-dimethyl-hydantoin.

Observations on the filter cake revealed that: (1) Filter cake thickness varied from zero to as much as ¼ inch. Thickest layers were along folds of the septum and thinnest in mid sections. (2) In areas with little or no filter cake (less than 1/16 inch), the surface of the septum and/or cake was black and not "clay" colored indicating that filtration had not taken place in these areas. The lack of precoat was due to folds of the septum being in contact. (3) Except for these sparsely-coated areas the septum had a thin layer of grayish clay colored material on the cake. The clay layer was thicker on one side of the septum than on the other. (4) There were a number of hair cracks in the cake which had penetrated to the septum. The sides of the hair cracks were coated with clay and a clay colored line on the septum indicated that unfiltered water had passed through these cracks. (5) The precoat at the bottom of septum housing was about ¼- to ½-inch thick.

The major drawback in the use of this type filter was the short duration of filter run. If a flow of less than one gallon per minute is considered inadequate, there are serious limitations to this filter, *i.e.*, only 2,000 to 20,000 gallons were filtered before a recharge was necessary (see footnote of Table 10). A second problem was contamination of the internal parts of the filter. Once the filter was contaminated with organisms either during recharging or by entrance of contaminated water, there was a tendency for the organisms to establish themselves in the filter. These organisms would then seed the effluent water.

TABLE 10.—Precoated Carbon Filter Test Data.

Run No.	Filter	Turbidity (units) Influent	Turbidity (units) Effluent	Apparent Color (units) Influent	Apparent Color (units) Effluent	Free Available Chlorine (mg/l) Influent	Free Available Chlorine (mg/l) Effluent	Total Gallons Filtered	Length of Filter Run (days)
1	OAES-20	33	28	87	79	—	—	8,327	27[1]
2	OAES-20	13	2	72	3	1.2	0.0	5,200	43[2]
3	OAES-20	7	2	24	9	0.52	0.03	19,340	82[3]
4	OAES-20	3	2	5	1	0.2	0.03	14,410	52[4]
5	OAES-20	6	3	9	5	1.47	0.09	22,820	77[5]
6	OAES-20A	8	5	16	14	0.45	0.09	12,520	35
						Free Available Brom-Chlor-Dimethyl-Hydantoin (mg/l)			
7	OAES-20A	12	5	29	13	8.04	1.16	19,580	50
8	OAES-20A	8	2	18	5	5.95	0.98	10,000	35[6]

[1] Flow less than 1 gpm after 14 days and 6,000 gallons filtered.
[2] Flow less than 1 gpm after 20 days and 2,000 gallons filtered.
[3] Flow less than 1 gpm after 55 days and 15,000 gallons filtered.
[4] Flow less than 1 gpm after 52 days and 14,000 gallons filtered.
[5] Flow less than 1 gpm after 63 days and 20,000 gallons filtered.
[6] Flow less than 1 gpm after 21 days and 10,000 gallons filtered.

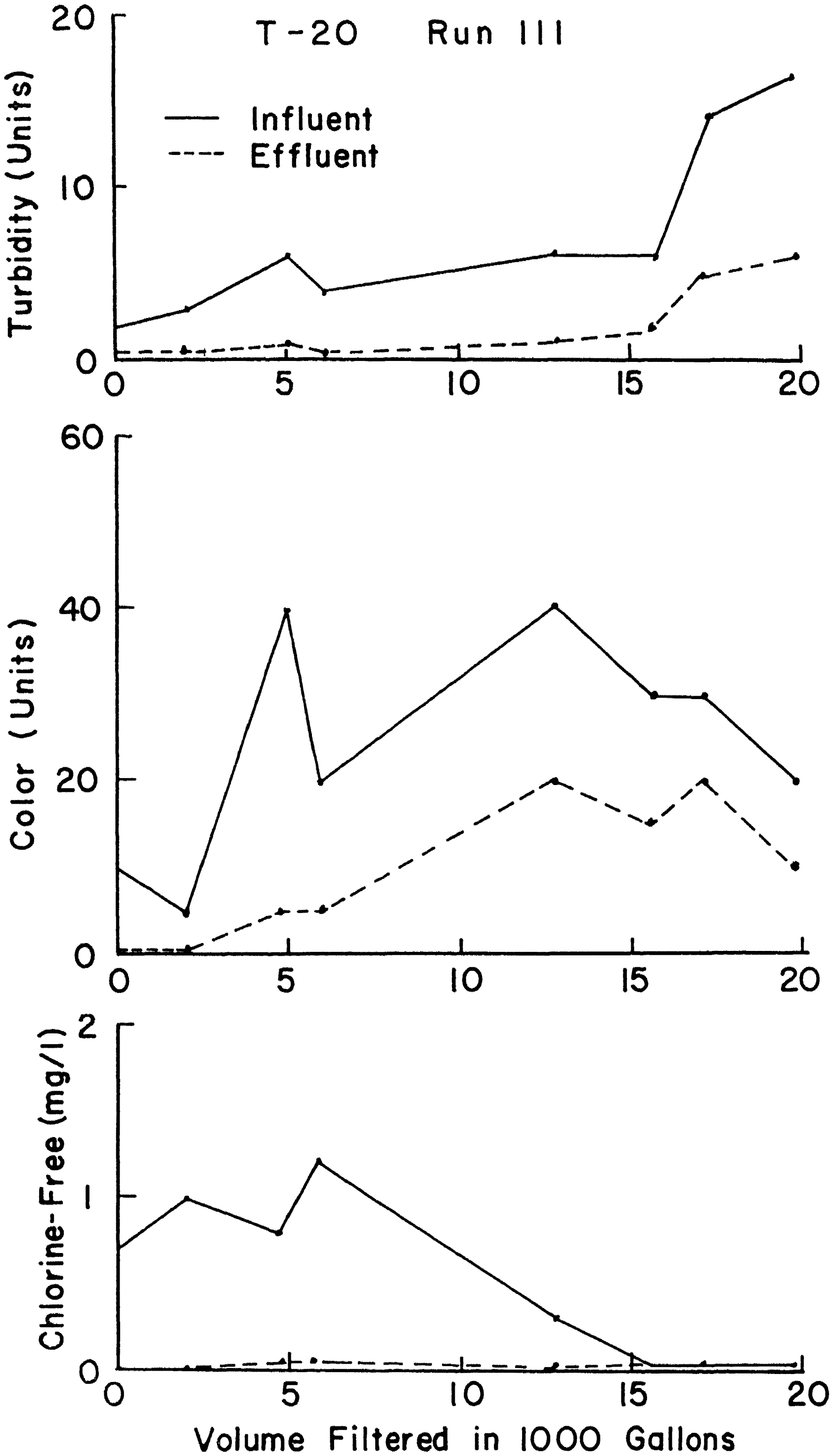

Fig. 14.—Filtration with a precoated carbon filter.

This situation could only be corrected by thorough cleaning and disinfection of the filter. It was also observed that in time microbial population would be eliminated if chlorinated water was fed continuously to the filter. This process, however, sometimes took as long as 2 to 3 weeks. Although this filter performed well in removing turbidity, color, odor, and chlorine, the short length of filter run and, therefore, high operating cost raises some uncertainty as to the suitability of this unit as a secondary filter of pond water. However, where influent water to the filter was of relatively high quality, the unit served as a good method for producing water with low turbidity, color, odor, and chlorine.

Pressurized Granulated Carbon Filters The pressurized granulated carbon filter appeared to have some merit as a pond water filter since carbon is widely used as an absorber of color and odor which are often problems in pond water. Carbon also is used as a media for dechlorinating water when high concentrations of chlorine are used for disinfection. The major uncertainity was whether granulated carbon would exert effective filtering action.

The granulated carbon filter unit tested was 16 inches in diameter and contained carbon granules ranging in size from ¼- to ½-inch. A backwash mechanism was incorporated into the design of the filter. Two filter runs were made. The first lasted 3 months with approximately 45 thousand gallons of water being filtered. During the second run 23 thousand gallons were filtered over a 2-month period.

During the first run the influent turbidity did not exceed 10 units or the influent color 40 units. Higher influent turbidities and colors were encountered during the second run (Table 11). The percentage

TABLE 11.—Pressurized Granulated Carbon Filter Test Data.

	OAES Filter Run 1	OAES Filter Run 2
Average Influent Turbidity, units	5.5	72.8
Percent Reduction in Turbidity	47	18
Percent Samples Meeting Standard[2]	100	0
Average Influent Color, units	13.7	74.2
Percent Reduction in Color (Apparent)	42	21
Percent Samples Meeting Standard[2]	92	0
Average Influent Chlorine, mg/l[1]	0.56	—
Percent Reduction in Chlorine	82	—

[1]Free and available chlorine.

[2]USPHS Drinking Water Standard 1946 for turbidity, 10 units; color, 20 units.

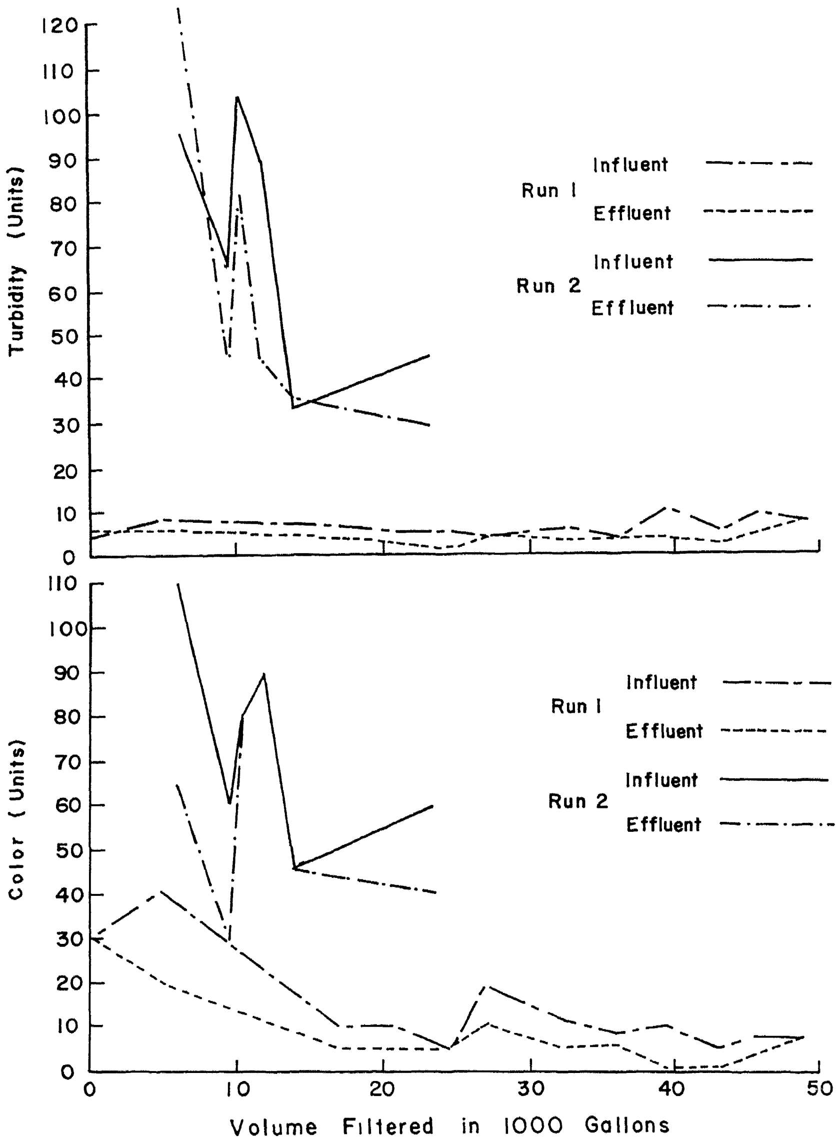

Fig. 15.—Filtration with a pressurized granulated carbon filter.

reduction of turbidity and color was greater during run 1. The high percentage of samples meeting the Standard in run 1 was due to the high quality of the influent water (Figure 17). None of the samples collected met the Drinking Water Standards during run 2. It is apparent from the data that this filter was not suitable under high turbidity and color conditions.

After the second run the carbon was removed from the filter. Even though the filter had been backwashed at regular intervals, the carbon was coated with a layer of sediment. This sediment undoubtedly reduced the absorption potential of the carbon. The large pores between the carbon granules probably caused the poor filtration.

From the results of these studies the granulated carbon filter is not acceptable as a primary filter of pond water. It may have some application as a secondary or polishing filter to remove true color and chlorine if an effective primary filter precedes it.

Disinfection

Brom-Chlor-Dimethyl-Hydantoin Poor results in the use of chlorine for disinfecting pond water supplies has been reported (2). For this reason investigations were made using other disinfecting agents. Bromine was not considered because of the danger in handling which often causes skin burns. However, a chemical containing both chlorine and bromide has been successful for swimming pool disinfection. This material is known as Brom-Chlor-Dimethyl-Hydantoin (BCDH).[6]

Chemical structure of this compound is shown in Figure 16 and its properties are as follows:

Appearance: white powder
Odor: faint halogen
Molecular weight: 241.5
Active Bromide: 33 percent
Available Bromide: 66 percent
Active Chlorine: 14 percent
Available Chlorine: 28 percent

The halogen carrier is 5,5-Dimethyl hydantoin. Studies by Dow Chemical Co. (15) and E. I. Dupont (16) showed that the carrier is

[6]Manufactured by Bromine Producers Div., Drug Research Inc. Adrian, Mich., under the name Dihalo and sold in a granular form under the name Sani-Flo Sticks.

Fig. 16.—Chemical structure of brom-chlor-dimethyl-hydantoin. (The relative positions of the active bromine and chlorine have not been established with certainty).

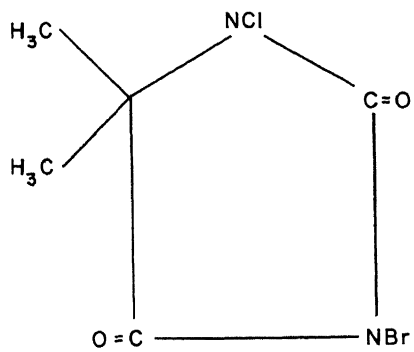

TABLE 12.—Destruction of E. coli with Brom-Chlor-Dimethyl-Hydantoin in Pond and Double Distilled Water.

Test No.	Water Used	pH	Initial Concentration of E. coli, per ml	Halogen Concentration, mg/l	Time for 99.5 Percent Kill, sec.	Time for 100 Percent Kill, sec.
1	Pond 60[1]	8.1	32,000	0.5	60	240
	D. D.[2]	8.0	18,000	0.5	60	240
2	Pond 60	8.1	189,000	0.5	60	>120
	D. D.	8.0	199,000	0.5	15	>120
3	Pond 8	8.7	39,000	0.5	30	60
	D. D.	8.3	5,000	0.5	<15	15
4	Pond 8	8.7	170,000	0.5	30	120
	D. D.	8.3	134,000	0.5	30	60
5	Pond 1	9.8	126,000	0.6	120	>120
	D. D.	9.3	60,000	0 6	<30	30
6	Pond 1	9.8	710,000	0.6	<30	60
	D. D.	9.3	110,000	0.6	15	120
7	Pond 5	9.4	139,000	0.6	>120	>120
	D.D.	9.5	71,000	0.6	60	>120
8	Pond 5	9.4	141,000	0.6	>120	>120
	D. D.	9.5	44,000	0.6	60	120

[1]Pond water samples taken one foot below surface seeded with E. coli.

[2]D. D.—Double distilled water seeded with E. coli.

very low in toxicity to animals and should present no problems at low dilutions in water supplies.

The bactericidal effects of BCDH on E. coli were studied by Mallmann and Davenport (17). Their conclusions were that in double distilled water at pH's between 4.85 and 7.2 and at a temperature of 25°C., a concentration of 0.5 ppm halogen kills bacteria effectively (15 seconds for 99.7 percent kill). It appeared to be a slightly more active germicide than sodium hypochlorite at identical concentrations. Other investigations revealed that bromide and chlorine were released immediately from the carrier upon dissolving in water.

Laboratory studies were conducted with pond water as well as distilled water. Both the pond water and distilled water were seeded with E. coli. A known amount of BCDH was added to both seeded pond and distilled water. At prescribed time intervals samples were neutralized with sodium thiosulfate. These samples were then incubated at 37°C. The results of this study are presented in Table 12.

TABLE 13.—Brom-Chlor-Dimethyl-Hydantoin Treatment Systems

Test No.	Sand Filter System	Point of Disinfection	Treatment System
1	Slow	Pre-filter	Barrel and gravel intake in pond, pump, BCDH feeder, filter, storage tank
2	Slow	Post-filter	Barrel and gravel intake, filter, BCDH feeder, storage tank
3	Slow	Post-filter	Same as No. 2
4	Slow	Post-filter	Surface intake, filter, BCDH feeder, storage tank
5	Rapid	Post-filter	Barrel and gravel intake pump, pressure tank, filter, BCDH feeder, 42-gallon tank filled with gravel employed as a contact tank
6	Rapid	Post-filter	Same as No. 5

The rate of E. coli destruction was lower with pond water than with double distilled water. With halogen concentrations of 0.5 to 0.6 mg/l at least 4 minutes or possibly more were necessary to assure a 100 percent kill of E. coli.

The BCDH feeder in field studies is shown in Figure 17. Water passed up through a section of pipe in the middle of the chemical basket and out through perforations in the pipe. The water then percolated down through the bed of BCDH and out through holes in the side of the chemical basket. The holes in the center pipe and basket were so located that a fairly constant halogen concentration was obtained at varying flow rates. Since the BCDH feeder contained air and acted as a pressure tank, the basket was not submerged when there was no flow through the feeder. A clear plastic top permitted the BCDH supply to be checked. The manufacturer recommended that new granules be added when the level dropped 1½ inches below the top of the basket.

Six test runs were made with the BCDH feeder in the field with various combinations of treatment equipment as shown in Table 13.

(**Test Run 1**) After being in operation just one week, a layer of slime formed on the BCDH granules (Figure 18). This slime originated in the raw water and caused a low BCDH concentration. When fresh BCDH granules were added, the BCDH concentration in the water increased. However, within a few days the slime layer formed and the concentration again decreased. This slime caused a wide variation and low concentration of BCDH (Table 14). A concentration of 1 mg/l of BCDH was effective in reducing coliform bacteria populations from 460 per 100 ml to a safe level (Table 14). The slow sand filter served as an effective contact vessel.

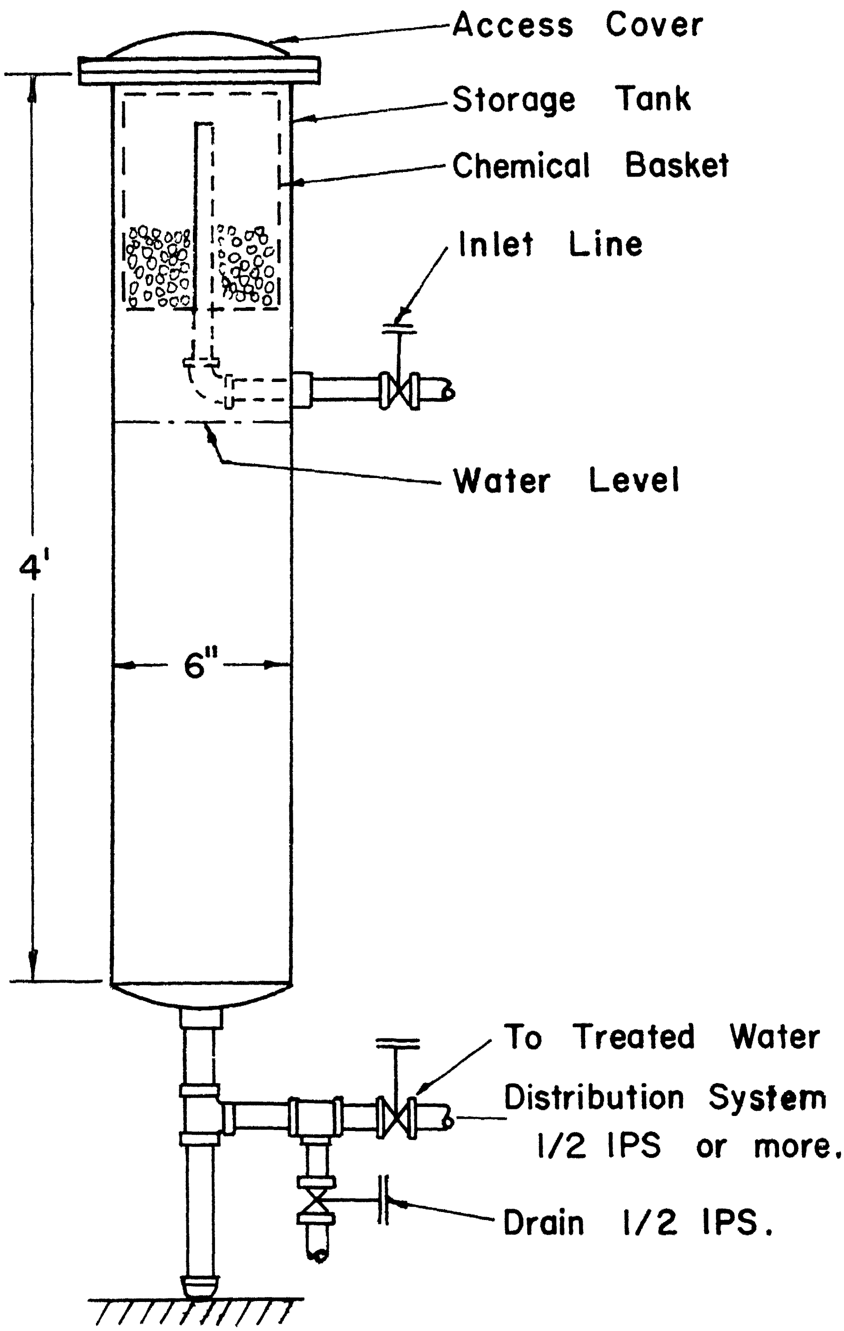

Fig. 17.—Brom-chlor-dimethyl-hydantoin-feeder.

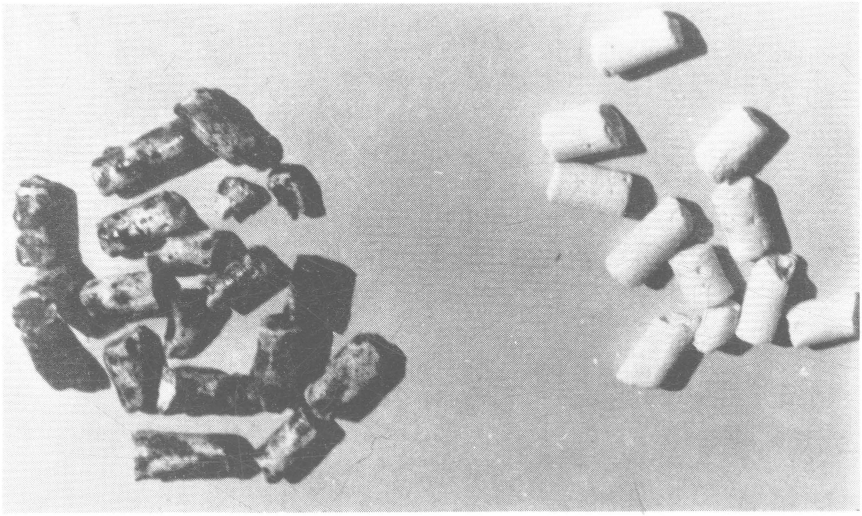

Fig. 18.—Brom-chlor-dimethyl-hydantoin granules. Left, with slime layer; right, new granules.

(**Test Run 2**) Water passing through the BCDH feeder during run 2 had been filtered and, therefore, had less demand for the disinfectant. As seen in Table 14 the BCDH concentration in the treated water was greater. Slime still formed on the granules, but did not develop as quickly or as thick a layer. Even though the water was receiving a higher concentration of BCDH, a larger percentage of the samples had high coliform populations (Table 14). The feeder did not provide time (estimated at 5 seconds) sufficient to reduce the coliform density to a safe level when 3.5 mg/l or less of BCDH was fed. However, samples taken from the distribution system, which had greater contact time, contained less than 3 coliform per 100 ml.

(**Test Run 3**) The flow rate of the water through the BCDH feeder was varied during this run. It was noted that flow rate had litte, if any affect on the BCDH concentration in the water. The BCDH level was higher during this run than in two preceding runs for some unkown reason. At the end of the run the turbidity of the water entering the feeder was very low, but the halogen concentrations were also lower than in earlier samples. A slime layer was noted on granules for the first part of the run, but none later. A high percentage of effluent samples contained less than 3 coliform per 100 ml even with only 1 mg/l of BCDH. This may have been because of the low coliform density of the influent water (Table 14).

TABLE 14.—Disinfection of Farm Pond Water with Brom-Chlor-Dimethyl-Hydantoin.

Test Run (See Table 13)	Free Available BCDH Concentration at Feeder (mg/l)[5]			Influent Coliform Density MPN/100 ml			Effluent Coliform Density MPN/100 ml[2]			Percent Contaminated Samples[6]
	Maximum	Minimum	Average	Maximum	Minimum	Median	Maximum	Minimum	Median	
1	4.8	0.5	1.99	460	3	11	>11,000[1]	<3	<3	22
2	6.7	0.2	2.9	93	3.6	23	43	<3	3.6	67
3	10.0	0.1	3.2	23	<3	<3	3.6	<3	<3	5
4	8.0	0.6	2.4	15	<3	<3	9.1	<3	<3	33
5	12.0	1.2	6.2	1100	<3	43	3.6	<3	<3	6
6[3]	8.5	0.8	3.6	93	3.6	9.1	240	<3	<3	17
6[4]	5.6	1.2	2.7	21	<3	3.6	9.1	<3	<3	29

[1]Probably sample was contaminated during or after collection.
[2]Estimated halogen-water contact time 5 seconds.
[3]Samples taken before sand filter and gravel filled contact tank backwashed.
[4]Samples taken after sand filter and gravel filled contact tank backwashed.
[5]Orthotolidine reading taken within 10 seconds.
[6]Contamination indicated by a coliform MPN higher than 3.0

(**Test Run** 4) BCDH concentrations were low (average 1.5 mg/l) during the first half of this run, but increased in the last half (averaged 4 mg/l). Corresponding with the increase in BCDH concentration was a decrease in turbidity and color. The BCDH demand of the water caused the variation in BCDH residual. A total of 170 thousand gallons was treated during this run with the use of 6.05 pounds of BCDH granules. At $1.25 per pound for the granules, the cost of BCDH would be $0.40 per 1,000 gallons. The short contact time in the feeder was again apparent during this run. Four samples with BCDH content greater than 4 mg/l, with turbidity and color low, and temperature high, were contaminated. Additional contact time supplied by the storage tank resulted in the destruction of coliforms in all but 2 samples. These organisms survived in spite of a BCDH residual of 1.8 and 5.6 mg/1, respectively. Tests made on the pH of the water before and after the BCDH feeder showed that the pH has changed by less than 0.2.

(**Test Run** 5) The flow rate during this run was higher (2 to 6.7 gpm) than in previous runs, but the flow rate did not cause the high BCDH concentration that was detected in the water (Table 14). A satisfactory explanation for the higher concentration was not obtained. The cost of BCDH to treated water in this run was 10.6 cents per 1000 gallons. In run 5 the influent coliform density was higher than in any of the other runs (Table 14) while on the other hand the average effluent density was one of the lowest. These good results were primarily because of the higher BCDH concentration.

(**Test Run** 6) Samples were taken just prior to and shortly after backwashing the sand filter and gravel-filled contact tank. The pre-backwash samples gave information on the operation of the BCDH feeder under dirty filter conditions and the post-backwashing samples under clean filter conditions. For the majority of the samples the BCDH residual was greater under the clean filter condition. The slightly higher turbidity under dirty filter conditions may account for this difference. During this run BCDH residual varied greatly from week to week for no apparent reason. Neither turbidity, color, pH, temperature or flow rate could be related with this variation.

Data for the six test runs are summarized in Table 14. Brom-Chlor-Dimethyl-Hydantoin was comparable with chlorine alone as a disinfecting agent. BCDH concentrations of up to 5 mg/l did not produce objectionable odors or tastes indicating that even higher concentrations could be maintained in the water. The contact time could

TABLE 15.—Effect of BCDH Disinfection upon Bacteria Population in Pond Water.

Test Run		Total Bacteria SPC/ml		Thermodurics per ml		Thermophiles per ml		Psychrophiles per ml		Enterococci MPN/ml	
		Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
2	max.	—	2400	—	81	—	>3000	—	8000	—	9.2
	min.	—	40	—	7	—	1	—	<1	—	<1.8
	med.	—	100	—	20	—	2.5	—	43	—	2
3	max.	—	250	—	130	—	1	—	30	—	11
	min.	—	<10	—	4	—	<1	—	<1	—	<1.8
	med.	—	170	—	12	—	<1	—	1	—	1.8
4	max.	—	1300	—	34	—	20	—	103	—	43
	min.	—	10	—	1	—	<1	—	<1	—	<3
	med.	—	50	—	17.5	—	4	—	1	—	<3
5*	max.	320	1000	21	18	6	5	29	2	3.6	3.6
	min.	70	<10	2	<1	<1	<1	<1	<1	<3	<3
	med.	225	20	8	5.5	<1	1.5	<1	<1	<3	<3
6*	max.	240	150	38	29	9	<1	3	<1	3.6	<3
	min.	40	10	4	2	2	7	<1	<1	<3	<3
	med.	125	30	12.5	10	6	2.5	<1	<1	3	<3

*Six samples of influent and 16 samples of effluent were analyzed in run 5, while in run 6 an equal number of influent and effluent samples were analyzed.

then be further shortened. Contact times greater than 4 minutes would seem desirable for good disinfection at 5 mg/l.

Additional studies of the destruction of bacteria in other physiological groups are reported in Table 15. These data show that the already relatively low bacterial populations in the raw water were reduced to an acceptable level by the halogen.

Chlorination Disinfection with chlorine was tested in conjunction with the slow sand filter and the pressure sand filter. Operational details of the nine test runs are presented in Table 16. Diaphragm pumps manufactured by three different companies, a tablet hypochlorinator, an interrupted suction chlorinator, and an aspirator chlorinator were evaluated (Figure 19).

In test run 1 chlorine was fed between the slow sand filter and storage tank. This procedure was followed in order to evaluate its effectiveness in bacteria elimination and to study methods for controlling the operation of the chlorinator. At first, chlorinator operation was controlled by a float valve and microswitch in the storage tank. This method was unsatisfactory, resulting in too much or too little chlorine residual (in many cases no chlorine residual). A liquid level control in conjunction with a solenoid valve was later installed and proved effective.

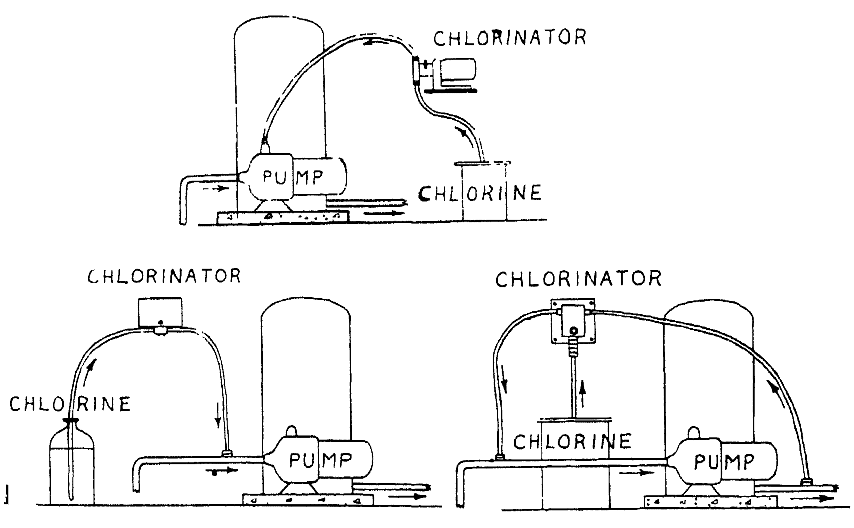

Fig. 19.—Chlorinators. Top, diaphragm pump; lower left, interrupted suction; lower right, aspirator. (Courtesy M. L. Palmer).

TABLE 16.—Chlorination Treatment Systems.

Test Run	Sand Filter System	Point of Disinfectant Application	Type Feeder	Treatment System
1	Slow	Post-filter	Diaphragm pump	Intake, filter, chlorinator, storage tank
2	Slow	Pre-filter	Diaphragm pump	Intake, chlorinator, filter, storage tank
3	Rapid	Pre-filter	Interrupted suction	Intake, chlorinator, pump, pressure tank, filter
4	Rapid	Pre-filter	Diaphragm pump	Intake, pump, chlorinator, pressure tank, filter
5	Rapid	Pre-filter	Tablet suction feeder	Intake, chlorinator, pump, pressure tank, filter
6	Raoid	Pre-filter	Aspirator	Intake, chlorinator, pump, gravel-filled tank, pressure tank, filter
7	Rapid	Pre-filter	Interrupted suction	Intake, pressure tank, gravel-filled tank, filter, chlorinator
8	Rapid	Pre-filter	Diaphragm pump	Intake, chlorinator, pressure tank, gravel-filled tank, filter
9	Rapid	Pre-filter	Diaphragm pump	Intake, chlorinator, alum feeder, gravel-filled tank, filter

During test runs 3, 4, and 5, 3 different types of chlorinators were studied under conditions normally employed in pressure rapid sand filter systems, *i.e.,* chlorine fed at the pump with the pressure tank, filter and its connecting pipe acting as contact vessels. In run 6 through 9 a 42-gallon tank filled with coarse gravel was added to the system to increase contact time.

A summary of the results of the 9 test runs is presented in Table 17. A brief discussion of each test run follows.

(**Test Run 1**) The coliform count detected immediately after chlorination was a result of insufficient chlorine-water contact time and lack of chlorine residual. The 900-gallon storage tank provided enough additional contact time to destroy the remaining coliform bacteria in the majority of cases. However, in a few cases when the residual was low in the stored water, it appeared that the water was recontaminated.

(**Test Run 2**) During this run the chlorine was added prior to the filter. The coliform density immediately after chlorination was less in run 1 because of the greater chlorine residual. Coliform organisms were found in the filter effluent until the chlorine demand of the filter had been satisfied and a relatively higher chlorine residual was obtained

TABLE 17.—Summary of Chlorinator Disinfection.

	Test Run Number								
	1	2	3	4	5	6	7	8	9
Influent Coliform Bacteria (MPN/100 ml)									
Maximum	2400	1100	1100	1100	43	93	150	2400	240
Minimum	<3	<3	<3	<3	<3	<3	15	<3	<3
Median	14.5	20	3.6	150	22	9.1	21	20.5	9.1
Coliform Bacteria Immediately after Chlorination (MPN/100ml)									
Maximum	93	29	3.6	150	9.1	23	150	91	7.3
Minimum	<3	<3	<3	<3	<3	<3	<3	<3	<3
Median	3.6	<3	<3	<3	—[1]	<3	<3	<3	<3
Coliform Bacteria after Contact Vessels (MPN/100 ml)									
Contact time, min.	—	360	4	4	4	9	9	9	9
Maximum	11,000	>1100	210	1100	21	3.6	240	93	<3
Minimum	<3	<3	<3	<3	<3	<3	<3	<3	<3
Median	<3	<3	<3	<3	—[1]	<3	3.6	<3	<3

[1]Only two samples collected.

TABLE 17. (Continued)—Summary of Chlorinator Disinfection.

	Test Run Number 1	2	3	4	5	6	7	8	9
Free Available Chlorine Immediately after Chlorination mg/l)									
Maximum	6.0	>4.0	2.4	10	25	1	3	1.8	4.5
Minimum	0	0.5	0.1	0.2	0	0	0	0	Trace
Average	2.1	>4.0	0.83	1.58	7.1	0.57	0.67	0.69	1.76
Free Available Chlorine after Contact (mg/l)									
Maximum	>9.0	>4.0	1.0	2.8	25	2	5	1.2	4
Minimum	0	0	0	0	0	0	0	0	Trace
Average	1.67	0.3	0.31	0.47	7.4	0.58	1.17	0.30	0.89
Percent Samples without Free Available Chlorine Immediately after chlorination	10	0	0	0	43	0	43	6	0
Percent Samples with Coliform Bacteria Immediately after Chlorination	70	37	25	50	50	25	40	17	20
after Contact	44	30	37	50	50	25	83	27	0

in the effluent. After the breakin period, no further effluent samples contained coliform bacteria. For further discussion on this test run see the section on slow sand filters.

(**Test Run** 3) During this test the pressure tank and pressure sand filter provided contact time of about 4 minutes. Problems were encountered in maintaining a constant chlorine residual in the water because of the positive pressure on the suction side of the pump. The interrupted suction type feeder operation depends upon a negative pressure on the suction side of the pump. The coliform bacteria detected immediately after chlorination and after the sand filter were a result of either insufficient chlorine residual or contact time. Waters containing coliform bacteria all had Ct factors of less than 4.

(**Test Run** 4) The only variation between runs 3 and 4 was the removal of the interrupted suction chlorinator and the installation of a positive displacement chlorinator. Coliform bacteria were detected only in samples that had Gt Factors less than 3. Again insufficient chlorine residual appeared to be the cause. A Ct factor of 6 is normally considered necessary for good coliform bacteria kill.

(**Test Run** 5) A tablet hypochlorinator was evaluated during this test. The major problem with this chlorinator was that the chlorine dosage could not be closely controlled. As seen in Table 17, the chlorine residual varied from 25 to 0 mg/l. A residual in the range below 4.8 mg/l could not be obtained. Adjustments of the feeder in an attempt to lower the residual resulted in insufficient chlorine being fed to meet the demand of the water, or in no chlorine at all. At the high chlorine residuals, coliform bacteria were destroyed.

(**Test Run** 6) A gravel filled tank was added to the system for this run, increasing contact time by 5 minutes. Difficulties were encountered with the aspirator type chlorinator primarily due to sediment plugging the small orifice in the venturi tube and stopping chlorine feed. Only one sample contained coliform bacteria and this occurred when the chlorine residual was zero.

(**Test Run** 7) The same chlorinator used in test run 3 was again evaluated in this test, but with provisions for greater contact time. The suction problem discussed earlier was more prevalent during this run resulting in a larger percentage of the samples with no chlorine residual. With little or no chlorine in the water, it appeared that the water was recontaminated during passage through the sand filter.

(**Test Run** 8) The varying chlorine demand of the water resulted in an erratic chlorine residual. However, when the Ct factor was maintained above 5, coliform bacteria were not detected in the effluent. A chlorine residual of 0.6 mg/l was required for Ct to equal 5.

(**Test Run** 9) Alum was fed to the system during this run, resulting in a lowered pH of the water. Normally chlorine is a more effective bactericide at low pH's. With alum feeding, coliform organisms were killed in 9 minutes of contact time, but not in 4 minutes.

The major problems in obtaining good disinfection with chlorine were inadequate contact and/or low chlorine residual. Samples taken immediately after chlorination (minimum of contact time) often still contained coliform bacteria even though they contained the chlorine residuals commonly recommended. The addition of a pressure rapid sand filter to the system increased the contact time about 4 minutes making it possible to obtain coliform kill with a chlorine residual of 1.5 mg/l or more. A 42-gallon gravel filled tank further increased the contact time and reduced the chlorine residual needed for coliform destruction to 0.6 mg/l. The results of this study corroborated the fact that a Ct factor of 6 was required for destruction of coliform bacteria.

Except for minor mechanical problems, all of the chlorinators observed were effective in feeding chlorine, with the exception of the tablet hypochlorinator. None of the chlorinators maintained a constant chlorine residual in the water. Since chlorine was being added to water with a constantly varying chlorine demand, the chlorine residual of the water varied with the demand. The pump on the rapid sand filter system had a positive pressure head on the suction side, therefore, the interrupted suction chlorinator under static conditions, did not always work satisfactorily.

Deposits of sediment in the tubing and valves also caused trouble in all feeders except the suction chlorinator. These deposits reduced flow rate and caused valves to stick. The addition of Calgon to the chlorine solution solved this problem except in the case of the tablet feeder.

The small venturi orifice in the aspirator type chlorinator was susceptible to plugging by sediment from the raw water. This was the major difficulty noted with this chemical feeder.

The tablet hypochlorinator operated very poorly. Chlorine feed rates were difficult to adjust. It was often a case of too much or too little chlorine. The 70 percent calcium hypochlorite tablets produced a large quantity of sediment that caused problems in lines and valves.

SUMMARY

Methods of filtering and disinfecting farm pond water were studied for a three-year period. A slow sand filter and pressure rapid sand filter were evaluated as primary filters and a cartridge, precoated carbon and granulated carbon filter as secondary filters. Disinfection studies were carried out with brom-chlor-dimethyl-hydantoin and chlorine as disinfecting agents.

The slow sand filter proved to be effective in the removal of turbidity and apparent color at flow rates between 15 and 150 gallons per day per square foot, except during a period of high rainfall and heavy runoff in the early spring (February, March, and April). The small size of the suspended particles was the primary cause of poor filtration. Filtration took place primarily in the schmutzdecke, but particles penetrated as deep as 8 inches into the sand. Bacterial densities were decreased by the filter alone, but not to an acceptable level. Prechlorination increased the length of filter run but did not improve filter performance other than in bacteria removal. A fiber glass mat placed on top of the sand filter did not improve its performance.

Pressure rapid sand filters were not effective in removing turbidity or apparent color. Filtration was markedly improved when alum was added to the water at the rate of 50 mg/l ahead of the filter. A rapid sand filter can also be employed as a contact vessel for chlorine and water. However, the filter will lower the chlorine content.

The cartridge and granular carbon filter performed poorly as secondary filters. On the other hand, the precoated carbon filter was effective in reducing the turbidity and apparent color to an acceptable concentration. The short filter life would limit its use because of frequent maintenance.

Similar efficiencies in bactericidal action were obtained with chlorine and BCDH (brom-chlor-dimethyl-hydantoin), an organic complex which releases both chlorine and bromine into water. With both chemicals poor results were obtained when the contact time between disinfectant and water was short and/or the disinfectant residual was low. The advantage of BCDH was that greater residuals were possible without developing bad odors and tastes. A filter preceding the BCDH was necessary to prevent the formation of a slime layer on the granules.

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